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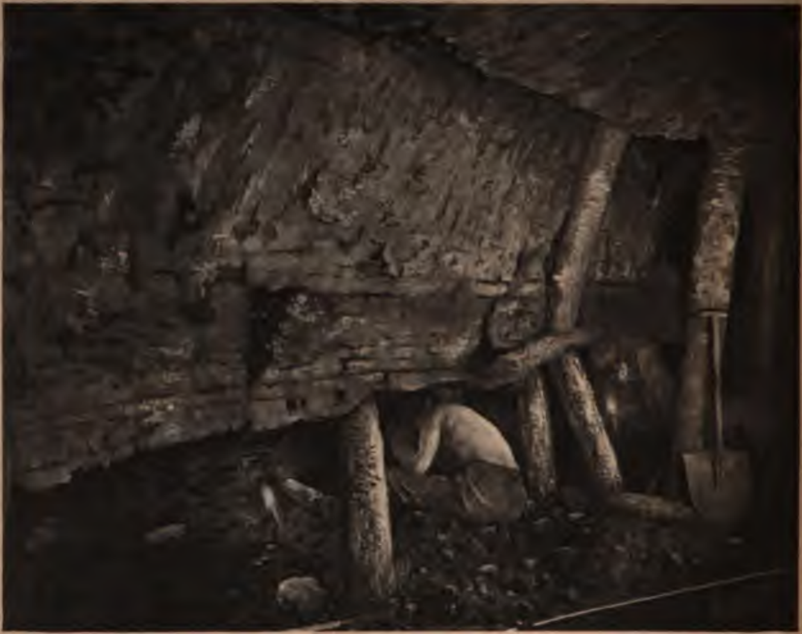

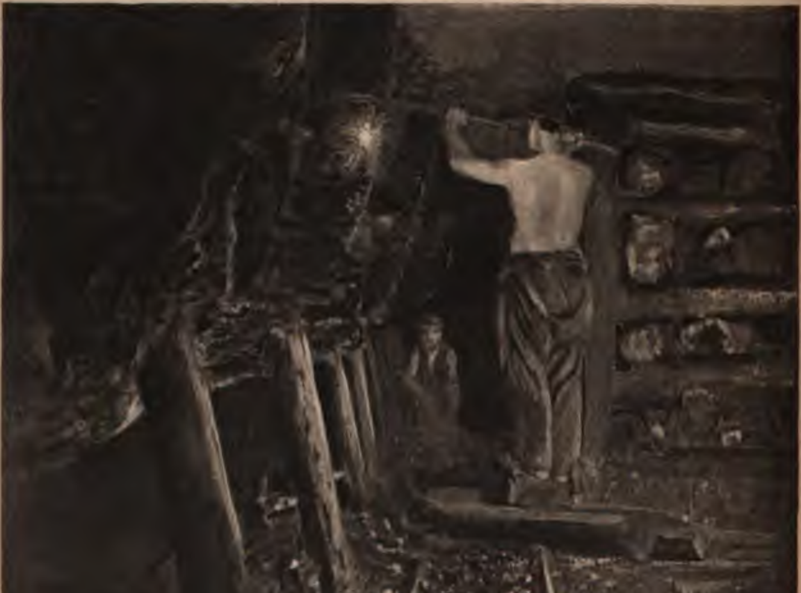

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A TEXT-BOOK

OF

COAL-MINING.

FOR THE USE OF COLLIERY MANAGERS
AND OTHERS.

BY

HERBERT W. HUGHES,

ASSOCIATE OF THE ROYAL SCHOOL OF MINES; FELLOW OF THE GEOLOGICAL SOCIETY;
ASSOCIATE MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS; CERTIFICATED
COLLIERY MANAGER; PAST-PRESIDENT OF THE BRITISH SOCIETY
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PREFACE.

In the preparation of this volume my aim has been to supply a text-book of moderate dimensions, giving all the information with which the student and the practical miner should be familiar. In order, however, to economise space, I have had to omit reference to many appliances which have become obsolete from their antiquity, or by reason of their failure in practice.

Although it is impossible within the limits of the book to furnish exhaustive descriptions on all points, yet the details of general colliery work have been fully described, on the ground that collieries are more often made remunerative by perfection in small matters, than by bold strokes of engineering. All modern collieries are practically identical so far as general machinery and arrangements are concerned; nevertheless, it frequently happens, in particular localities, that the adoption of a combination of small improvements any one of which viewed separately may be of apparently little value, turns an unprofitable concern into a paying one.

At the end of each chapter will be found a carefully selected list of Memoirs in which fuller information can be sought This will, it is hoped, prove a novel and useful feature in a treatise on coal-mining, for, scattered through the pages of the Transactions of the Mining Institutes, numerous valuable papers exist; but, owing to the lack of general indexes, they are unfortunately not consulted so much as they deserve to be.

All the figures elucidating the text have been specially drawn for this work, the majority having been reduced from original working drawings.

In conclusion, I have to express my cordial thanks to the many friends who have rendered valuable help in the preparation of the work. Especially, I am indebted to Mr. B. H. Brough, Assoc. R.S.M., F.G.S., Mr. H. G. Graves, Assoc. R.S.M., and Mr. H. F. Bulman, for important suggestions and able assistance while the volume was passing through the press.

HERBERT W. HUGHES.

CONEYGRE COLLIERY, DUDLEY,
September, 1892.

PREFATORY NOTE TO THE SECOND EDITION.

So short a time has elapsed since the issue of the First Edition, that any extensive alterations in the text are not required; but opportunity has been taken to correct a few literal errors, and in several cases to make additions. Four of the figures have been redrawn, and the Bibliography has been extended.

H. W. H.

DUDLEY,
May, 1893.

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ABBREVIATIONS.

The following abbreviations have been used to denote the publications most frequently quoted in this work.

The Roman numerals designate the volume, and the ordinary figures the page. For. Abs. = Foreign Abstracts.

SO. WALES INST.	Transactions of the South Wales Institute of Engineers.
SOC. IND. MIN.	Bulletin de la Société de l'Industrie Minérale de Saint Etienne.
CHES. INST.	Transactions of the Chesterfield and Midland Counties Institution of Engineers.
FED. INST.	Transactions of the Federated Institution of Mining Engineers.
BRIT. SOC. MIN. STUD.	Journal of the British Society of Mining Students.
N. E. I.	Transactions of the North of England Institute of Mining and Mechanical Engineers.
N. STAFF. INST.	Transactions of the North Staffordshire Institute of Mining and Mechanical Engineers.
INST. C. E.	Minutes of Proceedings of the Institution of Civil Engineers.
AMER. INS[illegible] E.	Transactions of the American Institute of Mining Engineers.
MAN. GEO. SOC.	Transactions of the Manchester Geological Society.
ENG. AND MIN. JOUR.	The Engineering and Mining Journal, New York.
SO. STAFF. INST.	Transactions of the South Staffordshire and East Worcestershire Institute of Mining Engineers.
REV. UNIV.	Revue Universelle des Mines.
MIN. INST. SCOT.	Transactions of the Mining Institute of Scotland.
MID. INST.	Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
ANN. DES MINES.	Annales des Mines.

TEXT-BOOK OF COAL-MINING.

CHAPTER I.

GEOLOGY.

The Study of Geology may be divided into two parts, one of which treats of inorganic matter, the laws to which such matter is subject, and the chemical and physical changes through which the crust of the earth has passed; the other deals with and investigates the order, character, and succession of organic life, and the relation which the various forms bear to each other. As no written records exist, which go back to the remote times when life first existed on our globe, the geologist has interpreted the changes which have taken place by careful observations of phenomena met with; and as histories of extinct races have been built up from the interpretation of hieroglyphics on monuments, so by similar results has the order of succession of geological strata been established from observations of the life forms preserved in a fossil state in the rocks which constitute the crust of the earth.

Rocks.—By this term is meant, not only large masses of coherent matter, as limestone, which build up mountains, but also the soft and loose gravels, or clay, which are found associated with them.

Classes of Rocks.—Rocks are divided into three classes—aqueous or stratified, metamorphic, and igneous or ejected.

Aqueous and Metamorphic Rocks.—These are made up of regular beds, or strata, and are probably all produced from the denudation of igneous rocks, although they appear to differ greatly from them. The great agent of disintegration is the atmosphere, and the rain which is precipitated from it.

Igneous Rocks.—These rocks may be broadly divided into four divisions, according to the quantity of silica they contain. First, they are separated into acid and basic; a third class is formed of rocks containing an intermediate amount of silica; while last of all there is a small, but important, class called "ultra-basic." To the acid type, containing on an average about 74 per cent. silica, belong granite and porphyry; while the basic type, containing an average of 50 per cent. silica, is represented by gabbro and basalts. The intermediate class (syenite, diorite, and some obsidians) contain on an average 60 per cent. silica (the ultra-basic, 39 per cent. silica) and a high proportion of alkaline earths and oxide of iron. Glassy varieties are common in the acid series, rarer in the intermediate series, and still rarer in the basic division.

Stratification.—When the fragments are large, the stratification, or bedding, is very imperfect, but if the particles are small, it is very perfect.

Laminæ.—When we have very close stratification, and get the thinnest paper-like layers in the planes of deposit of a stratified rock, it is said to be laminated.

Intrusive Rocks.—These are sometimes great masses forced up through the surrounding strata in no definite direction, or frequently, intrusive matter is forced along definite planes, forming *dykes*, where the sides are fairly parallel; a good example of this is the great whin-dyke of the North of England coal-field, which proceeds nearly ninety miles in a straight line. These intrusions were originally forced into their present position in a molten condition, evidence of which is afforded by the way they have altered the adjoining strata, coal seams in many instances being charred and rendered worthless for several yards on either side. It may happen that only the upper side of the stratified rocks below the igneous bed will show signs of baking, from which it is seen that the lava-flow was contemporaneous or interbedded with the rocks, while, if both the upper and lower surfaces of the beds are affected, the lava-bed was certainly intrusive.

The rocks of the globe present very different appearances to the gravels and sands which are formed every day on our sea-shores and at the mouth of rivers. All the stratified rocks have been originally deposited in a manner similar to that now going on, but changes have taken place in them subsequent to formation.

1. **Induration.**—In the depths of the earth's crust, by the long-continued pressure of "miles" of strata above a bed compose of finely divided particles, the effect is very great. In this wa muds pass into finely laminated clays, and finally into shal The effect of induration is well shown in the white limestone Antrim, which was originally formed in the same manner the English chalk, but, owing to the superposition of at l 2000 feet of basalt, has been hardened into a hard splin rock, showing no trace of chemical action. Induration is, ever, greatly aided by chemical action, the particles forming rock being cemented together by substances deposited from

tion in water. At great depths the rocks are undoubtedly saturated with water, and this facilitates the deposition of materials round the rock particles, or, as in the case of limestones, &c., the solution of some of the rock materials themselves, which are afterwards crystallised out from their solution in the water. Disintegration usually undoes all this work; the cementing material first yields, is removed, and the particles of the rock are set free again.

2. **Segregation.**—Again, segregation may be going on, particles of the rock separating from the remainder and segregating together, this being especially well seen in limestone containing silica; the particles of silica are drawn together by this action, forming the flints and cherts of the chalk.

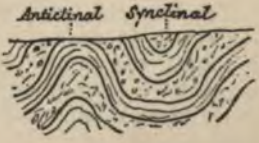
Fossilisation.—This is merely a case of segregation round organic matter. In many clay ironstones, the nodules of iron have been formed by the segregation of the mineral round fossil remains, and, on breaking open the nodule, the fossil is found inside, generally in a beautiful state of preservation.

Inclination of Strata.—Generally speaking, strata were laid down in a horizontal position, this being shown by the lie of pebbles in rocks, and by the position of fossil trees. It is, however, very rare to find the beds retaining this position, though the folding may be of the slightest. If a bed is at all inclined, it must reach the surface somewhere, and the space where this happens is said to be the *outcrop* of the bed. The nature of the outcrop and its width, depend on the thickness of the bed and the degree of inclination; it cannot be less than the thickness of the bed, and is wider, the smaller the angle of inclination.

In order to define a bed, two things must be known—first, the direction in which the inclined bed reaches the surface, and the inclination of the bed. The angle which beds make with the horizon is called the *dip*, and the line in a horizontal plane, the *strike*, the latter necessarily being at right angles to the dip. When the surface of the ground is horizontal, the lines of outcrop and strike coincide, but, if the strata are inclined, the outcrop is inclined also; the strike is always horizontal. Angles of dip are usually measured by an instrument called a clinometer, but, in doing this, care must be taken to distinguish between the true and apparent inclination; the latter can never be greater than the former, but it may be less to any amount.

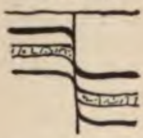
When the strata are bent in arches, they are said to have a synclinal fold, when the arch is downwards; an anticlinal, when the arch is upwards (Fig. 1); when the folds are small, they are called troughs and saddles respectively.

FIG. 1.



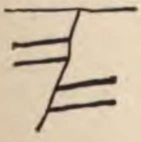
Faults.—When the pressure is too great, or is applied suddenly, or if the rock refuses to yield, and then breaks, instead of bending, a dislocation is obtained; the divided segments are thrown out of level, and do not fit, one side being higher than the other. This is called a fault. In mining districts, such term is applied loosely to anything which interferes with the seams that are being worked. Generally speaking, when contortions of the strata are numerous, faults are few; and *vice versâ*. The position of every fault is defined by two directions, as in the case of beds; the strike of a fault is spoken of, but, in the place of the word "dip," the term *hade* is employed, this being, however, the inclination measured from the *vertical*. To determine a fault accurately, it is necessary to know two other things—(1) which side is throw-up, and which is throw-down; (2) the amount of displacement. The former is in the majority of instances easily determined, as faults usually hade or incline towards the down-throw, so that in driving roads under ground, if the fault is first met with in the roof it is a down-throw, while if struck on the floor first, it is an up-throw. Again, rocks before breaking usually yield to bending a little, and such signs are very useful to the miner, especially where the hade of fault is nearly vertical (Fig. 2). No rule can give the amount of displacement, as sometimes, when the hade is small, the throw is large, and at other times, with a similar hade, the displacement is small. The throw of faults is always measured vertically, and may be variable at different points, often changing from a few feet at one end to hundreds of yards at the other. In addition, there is often a variation in the throw of the same fault at different levels. When the amount is small, they are called hitches, troubles, or slips.

FIG. 2.



Reversed Faults.—It has been observed above, that ordinary faults incline to the down-throw, but in rare instances they incline towards the up-throw, and are then said to be overlap or reversed faults (Fig. 3). The most noteworthy of this class in our own country, is the overlap fault of the Somerset coal-field, which occurs in the Countess Waldegrave's colliery at Radstock; by it, the seams of coal are doubled for a breadth of about 150 yards, the alteration in level amounting to 44 yards.

FIG. 3.

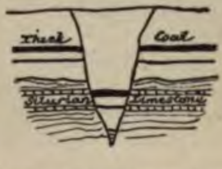


The dislocated walls of a fault are often in contact with each other, but frequently, especially when the beds are of varying hardness, spaces are left between filled with broken fragments which have been removed from the adjoining rocks. The distance across a fault may therefore vary from a few feet to many yards.

When the rocks are very hard and the fault is a clean-cut one, we get a remarkable polishing of the sides, known as "slickensides," caused by the enormous pressure of the rocks on each other during the displacement of the beds.

Trough Faults.—These are caused by two faults, each having a down-throw towards the other. A very good example of this is the Dudley Port Trough Fault, of the South Staffordshire coal-field (Fig. 4). Here two faults are separated from each other by half a mile—one a down-throw to the south, and the other a down-throw to the north. Each hades towards the other, so that they meet at no great depth, and, as the throw is equal and opposite at the point of meeting, no dislocation takes place.

FIG. 4.



Conformable and Unconformable Strata.—Subsidence has taken place in all times, but when this action was uniform, bed succeeded bed in regular order, and produced what are called conformable strata (Fig. 5). When, however, the beds were tilted up before the succeeding layer was deposited on them, or, as in many instances, the older beds were in addition denuded or worn away, the strata are said to be unconformable to each other (Fig. 6).

FIG. 5.

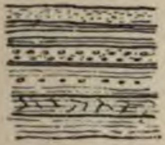
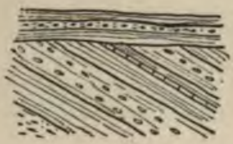


FIG. 6.



Joints in Rocks.—The bedding of a rock is produced during deposition, but there are other parallel structures produced by forces acting on it subsequent to formation. One system of divisional planes running through most stratified rocks, and which is entirely independent of the bedding, is that called *joints*. There are generally two systems of joints at right angles to each other, one better developed than the other, the first being called the master joints, and the other the secondary joints. These joints tend to break up what would otherwise be a continuous mass into rectangular blocks. Sandstones, granites, and rocks which do not easily undergo solution in water have closed joints, while limestones, &c., which are easily soluble, have open joints. The force which produced these divisional planes must have been very great, for pebbles of quartz lying in the direction of the joint planes are always found split right through. Not only do sedimentary rocks exhibit jointing, but some igneous rocks frequently possess this structure in a marked degree. Generally the joints are very irregular, but many igneous rocks, especially basalts, have developed columnar jointing. The reason for a rock splitting into columnar structure is not hard to discover; a mass of fused matter, on cooling down, tends to split, and, if of large extent, has no special form to follow, and therefore divides into the easiest forms, either the triangle, square, or hexagon. Three cracks only are required for the latter, so hexagonal columns are generally found.

The divisional planes, called *cleat* by the miner, which run through coal nearly at right angles to each other, and subdivide it into rectangular fragments of varying size, are referable to jointing, but it differs from ordinary jointing, inasmuch as it is carried to small subdivisions.

Cleavage.—Under the influence of great pressure, the particles of which a rock is composed, which usually have a long and short axis, tend to re-arrange themselves along the line of least resistance, thereby imparting to the rock a fissile structure, known to the geologist as cleavage, extending over large areas. Coarsely grained rocks never exhibit cleavage; it is best developed in argillaceous rocks, altered clays, and shales. As a rule, when a rock is cleaved, it loses its power of splitting along the bedding, the latter being completely obliterated by the force which produced the cleavage. Nodules and fossils which are included in cleaved rocks, are altered and distorted in a curious manner.

The order of succession has been divided into four great divisions—(1) archæan; (2) palæozoic, or primary; (3) mesozoic, or secondary; and (4) cainozoic, or tertiary; to which is sometimes added the quaternary, or recent. These divisions are split up into systems, each system into formations, which usually receive the name of places where they are well developed, and, finally, the formations are subdivided into beds, characterised in many instances by certain fossils being always associated with them.

The following summary shows the classification at present adopted:—

CAINOZOIC, OR TERTIARY.	Post-pliocene. Pliocene. Miocene. Oligocene. Eocene.	
MESOZOIC, OR SECONDARY.	Cretaceous. Jurassic. Triassic.	
PALÆOZOIC, OR PRIMARY.	Permian, or dyas.	
	Carboniferous.	Upper, middle, and lower coal measures. Millstone grit. Carboniferous limestone.
	Devonian.	
	Upper Silurian.	
	Lower Silurian. [illegible]	
	Cambrian.	
ARCHÆAN.—	Crystalline rocks, schists, &c.	

It must be observed, that these formations rarely succeed each other in the regular order given; breaks occur, caused by metamorphism and denudation, or by original non-deposition owing to local circumstances, and only by observations at numerous places has the order of succession been established.

The coal-miner is more interested in the carboniferous formation, that being the one in which beds of coal occur to the greatest extent all over the globe. In this country, with one or two small and rare exceptions, the whole of the coal mined is extracted from beds of the carboniferous strata. The greater part of the coal measures of Europe and the United States also belongs to the carboniferous system, but in the latter country large deposits of coal occur in the cretaceous formation, while a large portion of the New South Wales coal belongs to the triassic.

Carboniferous System in Britain.—This is divided into the following members:—(1) The *Coal Measures*, consisting of beds of shale and sandstone varying in thickness from 200 to 1200 feet, and containing numerous beds of coal. The coal measures proper, may be further subdivided into upper, middle, and lower divisions, each of which possesses characters more or less peculiar to it; no sharp line of demarcation has, however, been yet satisfactorily established between them, each passing insensibly into the other. One peculiarity of the upper coal measures is worth noticing—namely, the occurrence in them of thin beds of a fresh-water limestone, containing immense numbers of a small shell called the *Spirorbis carbonarius*, from which the beds are called spirorbis limestone. (2) The *Millstone Grit*, consisting of coarse sandstones. This received, in the South of England, the name of the "farewell rock," as it contains no coal seams in that part of the country. This rule, however, does not apply to every district, as, in the North of England and in Scotland, beds of coal and shale are found. (3) The *Carboniferous Limestone* contains in Scotland thin beds of coal. This portion of the carboniferous system is built up of thick beds of limestone of marine origin, full of the remains of animal life.

Fossils.—The coal measures contain in varied abundance the remains of luxuriant vegetation. As an example, may be cited the occurrence of the plant known to the geologist as *Lepidodendron*, which attained dimensions of from 40 to 60 feet high, and several feet ^in diameter. This plant is allied to the lowly club-moss of the present time, whose height does not exceed a few inches. Another example that may be referred to, is the jointed and fluted stems called *Calamites*, represented in our fields and marshes by the *equisetum*, or *horse-tails*. Portions of ferns are very abundant, some of which attained enormous dimensions. Remains of the stalks (rachis) of ferns have been met with, measuring in their compressed state 5 feet across, and Grand 'Eury describes the frond of a fern measuring 16 feet long. The classification of these ferns has always presented difficulties to the botanist, owing to the fragmentary manner in which they are found, but recent researches of Williamson and Kidston in our own country, Grand 'Eury, Schimper, Zeiller, and Stur on the Continent, and Dawson and Lesquereux in America, have greatly extended our knowledge of a most fascinating branch of geology, and one in which the mining student is most directly interested. A knowledge of the flora of the coal measures is essential to any one searching unknown districts for indications as to coal-bearing rocks, and it is not too much to say, that vast sums of money have been thrown away in fruitless attempts to prove coal to exist, where a little knowledge of the fossils of the carboniferous formation would have at once shown the uselessness of any search. The classification of these ferns has until lately been quite arbitrary, form of leaf and arrangement of nerves, being the points usually relied on. Living ferns are referred to their several classes, by the arrangement of their fructifications, which are usually borne in small rounded dots, called sori, on the back of the leaflets. Much knowledge has recently been gained of the fructifications of fossil plants, and hence a more reliable classification is the result.

Bibliography.—The following is a list of the more important memoirs dealing with the subject-matter of this chapter:—

The Coalfields of Great Britain, E. Hull, 4th Edition, London, 1881.

N. E. I.: *The Northern end of the Bristol Coalfield*, H. Cossham, x. 97; *Coal Mining, &c.*, N. Wood, J. Taylor, and J. Marley, xii. 149; *The South Wales Coalfield*, T. Forster Brown, xxiii. 197; *The Larger Divisions of the Carboniferous System in Northumberland*, G. A. Lebour, xxv. 225; *The Carboniferous Rocks of Cumberland and North Lancashire*, J. D. Kendall, xxxiv. 125; *A Further Attempt for the Correlation of the Coal Seams of the Carboniferous Formation of the North of England*, M. Walton Brown, xxxvii. 3.

SO. WALES. INST.: *The Southern portion of the Somersetshire Coalfield* G. C. Greenwell, i. 147: *Some of the Geological Problems in the Bristol Coalfield*, H. Cossham, xii. 84; *The Somersetshire Coalfield*, J. McMurtrie, xii. 424.

CHES. INST.: *Economic Geology of Derbyshire*, A. H. Stokes, vi. 60; *Geology of the South Derbyshire and East Leicestershire Coalfields*, G. S. Bragge, xv. 198.

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BRIT. SOC. MIN. STUD.: *Forest of Dean Coalfield*, H. R. Insole and C. Z. Bunning, vi. 61; *A Month's Visit to the North Staffordshire Coalfield*, A. W. Grazebrook, xiii. 127.

CHAPTER II.

COAL.

Definition of Coal.—The question, "What is coal?" appears a very simple one to answer, but that such is not the case, was proved by the now historical lawsuit over the Torbane Hill mineral in 1853. The owners of the Torbane Hill estate had leased all coal contained in it, and in the course of working, the lessees extracted a combustible material containing a large amount of gas. The lessor claimed that this mineral was not coal, and disputed the right of the lessees to work it. A trial resulted, and geologists, chemists, and gas engineers gave evidence on both sides. In summing up, the judge remarked, that "to find a scientific definition, after what has been brought to light within the last few days, is impossible." For our purpose, coal may be defined as a solid stratified substance, capable of undergoing combustion in contact with oxygen, not containing sufficient earthy impurities to prevent its being applied as a source of heat in furnaces and fireplaces, and varying in colour from brown to black.

Formation of Coal.—However much geologists may differ as to the question whether coal was formed on the spot on which the forests that produced it grew, or whether it resulted from the accumulation of drift, every one agrees that it results from the decomposition of vegetable matter. The hypothesis most generally accepted is the former, although it is perfectly clear that in a few isolated instances small areas of coal have been formed by organic matter drifted into lakes. The common-sense view, that the land became submerged at intervals, and that the underclays of coal seams form the beds on which the plants originally grew, is the great argument in favour of the *in situ* theory, as it is an everyday occurrence to find the roots of trees firmly embedded in the underclay. Exposed to the action of the atmosphere, vegetation decays and goes to enrich the soil, but supposing that the organic material fell into water, decay is incomplete, layer would be deposited on layer, and under pressure deposits of coal are formed. In peat bogs, for instance, living plants are found at the surface, lower down the forms of plants are still recognisable, while the bottom portion is very compact, and vegetable structure can scarcely be distinguished; as we go deeper in the mass the quantity of carbon increases. The conversion of woody tissue into coal takes place by the elimination of oxygen, which combines with carbon to form carbonic acid gas, and by the separation of carburetted hydrogen ("fire damp" of the miner) and water. To illustrate the gradual change in composition in passing from wood to anthracite coal, Dr. Percy * gives the following table, the proportion of carbon being estimated at the constant amount of 100:—

Substance.	Carbon.	Hydrogen.	Oxygen.	*Disposable*† Hydrogen.
Wood (the mean of several analyses	100	12.18	83.07	1.80
Peat " " " "	100	9.85	55.67	2.89
Lignite , " 15 varieties . .	100	8.37	42.42	3.07
Ten-yard coal of South Staffordshire	100	6.12	21.23	3.47
Steam coal from the Tyne . . .	100	5.91	18.32	3.62
Anthracite coal from Penn., U.S.A.	100	2.84	1.74	2.63

Note.—Certain bodies existing in Nature are composed of substances that cannot be resolved into any simpler form, these being called *elements* by chemists, and designated by symbolic abbreviations. The smallest indivisible parts of these elements are called atoms, and these, by combination with each other, form the substances occurring in Nature. The number of atoms of each element comprised in any substance, is shown in chemical formulæ, by a number following the symbol of each element. Thus, water contains one atom of oxygen and two of hydrogen, its chemical symbol being H_2O.

Classification of Coals.—The classification of the various coals occurring in the sedimentary rocks is best done by dividing them into heads according to the relation between the proportions of carbon and oxygen. In this manner, is obtained (1) Lignite, (2) Bituminous Coal, (3) Steam Coal, (4) Cannel, (5) Anthracite.

1. *Lignite.*—Found in our own country at Bovey Tracey, in Devonshire. Some varieties show distinct woody texture, while others are structureless. They contain a large proportion of water, burn with a disagreeable odour, and are brown in colour. Lignite coal contains about 67 per cent of carbon and 26 per cent. of oxygen. A subdivision of the class is sometimes made, called *brown coal*, which contains a larger proportion of carbon and less oxygen than the true Lignites. They occur in large quantities on the Continent and in some of our colonies, an analysis of brown coal from New Zealand showing, carbon 72.2, oxygen 22.4, hydrogen 5.4.

2. *Bituminous Coal.*—The proportion of carbon in this class varies from 75 to 90, and the oxygen from 6 to 19. They burn

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* *Metallurgy* (*Fuel*), *&c.*, 1875, p. 208.

† For definition, see p. 14.

with a more or less smoky flame, and are largely used for household purposes. As the proportion of oxygen decreases, the coal gets blacker and less sonorous, and the friability increases. The bituminous class of coals, may be further subdivided into non-caking and caking varieties ; the former, when burnt, split up into fragments, while the latter soften on the fire and swell up, the particles bind together, and form a pasty mass. This property is an extremely valuable one, and from this class of coal are made great quantities of coke. The small pieces are heated together in a suitable oven to a certain temperature, and when the mass is withdrawn and cooled, a hard glistening mass is obtained, in which all form of the original particles is lost. It has never been established, to what this property of caking is due, but it is certain that ultimate analysis forms no guide. M. Gruner gives the following analyses of two coals :

Caking

	(a)		(b)
Carbon	75.2	...	76
Hydrogen	4	...	4.3
Oxygen	16	...	16
Ash	3	...	3.3
Water	6.3	...	5.4

These coals are nearly identical in composition, but while (*a*) cakes, (*b*) does not. Chemists can determine the amounts of the various elements present in coal, but are quite unable to say how these elements are combined amongst themselves, these internal combinations being the probable explanation of the different behaviours of coals of the same ultimate analysis. For commercial purposes, proximate analysis is all that is required, this giving us the amount of fixed carbon (coke), volatile matters, and the amount of impurities. There appears to be no rule for determining the caking qualities of a coal, except actual experiment, as this property is possessed by coals differing widely in composition. It appears to be influenced by the method of conducting the experiment; thus, in some cases rapid heating will cake a non-caking coal. The amount of ash present does not seem to influence the result, as examples are known of a caking coal containing 20 per cent. of ash. On the other hand, many coals lose their power of caking by long exposure to the air.

(3) *Steam Coals.*—These are principally worked in the South Wales and North of England coal-fields. As their name denotes, they are mainly used for the production of steam ; their evaporative power is high and they give off scarcely any smoke in burning, while on account of their structure, they burn more readily than anthracite.

(4) *Cannel Coal.*—The chief deposits of this class occur in the Lancashire and Scotch coal-fields. Cannel is very rich in hydrogen, and is mainly used for the production of gas, as it yields by destructive distillation about 40 per cent. of volatile matters.

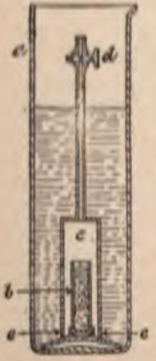
It is very hard, dense, and structureless, and is sometimes used for the manufacture of ornaments. In this division of coals may be included certain shales, containing large quantities of bituminous matters, which on distillation yield liquid and solid paraffin. The Boghead cannel, over which the celebrated trial took place, may be considered the representative of this type.

(5) *Anthracite.*—The darker and denser varieties of ordinary coal gradually pass into the anthracitic varieties, which are characterised by the large amount of carbon they contain. They do not soil the fingers, are very hard, and break with a conchoidal fracture. The formation of anthracite has probably been effected by the alteration of bituminous coals under heat and pressure. In the South Wales coal-field, the same seam of coal, which is of the ordinary bituminous variety in the eastern district, passes by gradations into steam coal in the middle of the coal-field, while in the western district it is changed into anthracite. Enormous deposits of this class of coal are met with in Pennsylvania, our own store being confined to South Wales. Anthracite contains from 93 to 95 per cent. carbon, 4 to 2 per cent. hydrogen, and 3 per cent. oxygen. It is practically smokeless when burning, and is much used where such a property is valuable, as, for instance, in malt-drying and in some metallurgical operations. The coke is brittle and useless for commercial purposes.

The following table* (p. 13) shows the percentage composition of different classes of coal.

Commercial Value of Coals.—The value of coal as fuel depends chiefly on the *Calorific Power*, which is the total heat developed by combustion, expressed either in units of heat or of evaporation, and by the amount of ash and impurities present.

FIG. 7.



In determining the calorific power of fuels, the same difficulty is met with, as in judging of the caking properties. The composition, and the units of heat developed by the combustion of each component of the coal, being known, the theoretical calorific power can be easily determined, but, as before, we neither know how the various elements are combined together, nor what quantities of heat appear or disappear during the breaking up of the complicated compounds of which coals are composed. Direct experiment is resorted to for the actual calorific power, the operation being performed in an instrument called a *calorimeter*. The most convenient of these for practical purposes, is the one designed by Mr. Lewis Thompson, which consists of a glass vessel (*a*, Fig. 7) containing a known quantity of water.

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* Compiled from Dr. Percy's *Metallurgy* (*Fuel, &c.*), London, 1875.

No. of Sample.	Nature of Coal.	Locality.	Specific Gravity.	Composition per Cent.							Coke.
				Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Water.	
1	Lignite .	Bovey Tracey, Devonshire	1.129	66.31	5.63	22.86	0.57	2.36	2.27	34.66	30.79
2	" .	Bodonspatak, Hungary	1.327	55.94	4.26	33.23	—	4.27	3.30	10.84	52.60
3	" .	Auckland, New Zealand	—	55.57	4.13	15.67	1.15	0.36	9.00	14.12	—
4	Bituminous	Thick coal, Wolverhampton, S. Staffs.	1.278	78.57	5.29	12.88	1.84	0.39	1.03	11.29	57.21
5	" .	Arley coal, Bolton, Lancashire . .	—	80.32	5.33	7.47	—	2.13	2.87	1.88	63.32
6	" .	Northumberland	1.276	81.41	5.83	7.90	2.05	0.74	2.07	1.35	66.70
7	" .	Aberdare, South Wales	—	85.74	4.54	3.57	—	0.81	4.64	0.70	76.10
8	Steam .	Merthyr, South Wales	—	86.80	4.25	3.06	—	0.83	4.40	0.66	84.42
9	" .	Llwynypia, South Wales	1.310	90.55	4.14	2.35	1.26	0.45	0.67	0.58	85.68
10	" .	Pontypool, Monmouthshire . . .	—	90.63	4.11	2.53	—	0.48	1.65	0.60	88.35
11	" .	Aix-la-Chapelle	1.343	91.45	4.18	2.12	—	—	2.25	—	89.40
12	Cannel .	Wigan	1.276	80.07	5.53	8.08	2.12	1.50	2.70	0.91	—
13	" .	"Lesmahago," Scotland	1.251	73.44	7.62	11.76	—	1.14	6.03	—	43.30
14	" .	"Boghead," Edinburgh	—	63.10	8.91	7.25	—	0.96	19.78	—	19.78
15	Anthracite	South Wales	1.392	90.39	3.28	2.98	0.83	0.91	1.61	2.00	—
16	"	South Wales, near Swansea . .	1.348	92.56	3.33	2.53	—	—	1.58	—	—
17	"	Pennsylvania	1.462	90.45	2.43	2.45	—	—	4.67	—	—

The nitrogen, when not quantitatively determined, is included in the number indicating oxygen.

The composition per cent. is calculated on dry samples in Nos. 1, 2, 4, 6, 11, 12, 13, 14, 15, 16, and 17, and water is included in Nos. 3, 5, 7, 8, 9, 10.

A weighed invariable quantity of the coal to be experimented with, is intimately mixed in a mortar with about ten times its weight of a mixture of three parts potassic chlorate and one of potassic nitrate. This mixture is placed in a small copper cylinder *b*, which in its turn is covered with another copper vessel *c*, furnished with a tube and stopcock *d* on the upper side, and pierced with holes *e* on the lower end. A fuse is placed in the smaller cylinder containing the mixture, this is lighted, the stopcock closed, and the apparatus let down to the bottom of the graduated flask containing the water. When combustion has ceased, the stop-cock is opened and the apparatus is moved gently up and down, care being taken not to raise it out of the water. The temperature is noted at the beginning and end of the experiment, and from a table supplied with each instrument, the calorific power is found. The rise of the temperature, plus 10 per cent. of this rise, will give the number of lbs. of water which 1 lb. of coal will convert into steam from and at 212° F. The importance of calorific power is not at all understood by consumers. One coal may be obtained for a less price than another, but if the lower-priced coal has less calorific power than the other one, the consumer may not be obtaining the best value for his money. Coals rich in oxygen never have such high calorific powers as those containing a smaller amount, as the quantity of hydrogen available for heating purposes in any fuel, is not the total amount of that element present, but only that portion of it (called *disposable* hydrogen) which is in excess of the quantity required to form water with the oxygen contained in the coal. The amount of disposable hydrogen in any coal can be ascertained, when its composition is known, by dividing the quantity of oxygen present by 8 and subtracting the result obtained from the total quantity of hydrogen present, the remainder being the disposable hydrogen. Calorific powers of a few coals are given in the following table:*

Locality.	Nature of Coal.	Calorific Power (in heat units), of dry Coal free from Ash.
Toula, Russia	Lignite	13,837
Manosque, Basses Alpes . . .	"	12,584
France and Germany . . .	Brown coal	11,340–14,220
England	Caking coal	15,804
"	" "	16,108
Basin of Donetz, Russia . . .	" "	15,651
Le Creusot, France	" "	17,319
" "	Anthracite	17,021
Basin of Donetz, Russia . . .	"	14,866

The ash of coals is the substance remaining when total combustion has been effected. It is composed of the earthy impurities originally present in the coal, and may be easily determined by burning a weighed quantity of coal in a porcelain crucible, either over a Bunsen gas-burner, or in a muffle. It is important that not only the *quantity* of ash should be determined, but also its *nature*. Some ashes tend to fuse together and form "clinker," which is very objectionable; more attention is required from the stoker, as he has to be continually stirring up the fire, and even when this is done thoroughly, the draught is materially interfered with, and imperfect combustion is likely to take place. Coal may contain such a large proportion of ash as to be practically worthless as a fuel. The amount of iron pyrites present has also a great effect on the nature of ash, as fusion is assisted and a tendency to form clinker results. Sulphur, too, which is contained in pyrites, is very objectionable in some metallurgical operations.

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* *Coal, its History and Uses*, 1878, p. 250.

Gases occluded in Coal.—The majority of coals contain various gases, which are given off when exposed to the atmosphere. Generally this takes place slowly, and may be observed by the singing noted at the working places in fiery seams of coal, or by the sudden outbursts of gas which are known to the miner by the name of "blowers." Certain coals of a porous structure readily yield up the gases contained in them, while others of a denser character, although containing even more gas stored in them, do not discharge it in such quantities. In vacuo, and under the influence of a gentle heat, coals readily discharge the gases they contain. Mr. J. W. Thomas* has made a series of experiments on this subject which throw a great deal of light on the question. He finds that the gases occluded from bituminous coals consist mainly of carbonic acid, and that the quantity yielded is very much smaller than that given off by the steam and anthracitic varieties. Steam coals evolve a large quantity of gas, the chief component of which is marsh gas, which in some instances reaches as high as 87 per cent. Anthracites yield by far the largest volume of gas, with a composition closely resembling that from steam coal. The following table* (p. 16) shows the quantities of gas evolved from coal at 100° C. (212° F.) in vacuo, and its percentage composition.

Mr. Thomas points out, that these results were obtained in a laboratory, and that it must not be supposed that coals which contain the greatest quantity of gas in their pores are the most dangerous to work, the rate of discharge being controlled, as has been before pointed out, by the structure of the coal. Anthracites, for instance, although holding large quantities of marsh gas, are by no means dangerous to work, as only small quantities of gas are discharged at the working face owing to the jet-like nature of these coals, such structure being eminently favourable to the retention of gas. On the other hand, steam coals, although containing a smaller quantity of gas, readily give it up, owing to their porous nature, and the quantity of gas evolved at the face of the workings in some of these coals is enormous. From these results we are able to see where the explosive gases in mines are obtained, and can readily understand that mine-gases and the gases occluded in the coal stand in definite and fixed relationship. Mr. Thomas experimented in this direction, and the results he obtained are summarised in the following table:—

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* *Coal, Mine Gases and Ventilation*, 1878. † *Op. cit.*, p. 345.

No. of Sample.	Nature of Coal.	Gas evolved by 100 grammes of coal at 100° C. *in vacuo.*	Composition of Gases.			
			Carbonic Acid.	Oxygen.	Marsh Gas.	Nitrogen.
		c.c.				
1	Bituminous .	55.9	36.42	0.80	—	62.78
3	" .	55.1	5.44	1.05	63.76	29.75
3a	Semi-bituminous	73.6	12.34	0.64	72.51	14.51
4	Steam . .	194.8	5.04	0.33	87.30	7.33
5	" . .	250.1	13.21	0.49	81.64	4.66
8	" . .	375.4	9.25	0.34	86.92	3.49
9	" . .	149.3	11.35	0.56	73.47	14.62
13	Anthracite .	555.5	2.62	—	93.13	4.25
14	" .	600.6	14.72	—	84.18	1.10

No. of Sample.	Whether a Blower or obtained by boring into Coal.	Composition of the Gas.			
		Marsh Gas.	Carbonic Acid.	Oxygen.	Nitrogen.
1	Blower	97.65	0.50	—	1.85
2	Boring	97.31	0.38	—	2.31
3	Blower	96.74	0.47	—	2.79
4	Boring	96.54	0.44	—	3.02
5	"	74.86	0.15	4.69	20.30
8	Blower	94.84	0.10	—	5.06
10	"	47.37	0.90	10.15	41.58
14	"	95.56	0.35	0.11	3.98

The enormous pressure under which these gases are contained in the coal will be realised when it is stated that in the 4-ft. seam of the Harris Navigation Colliery, at a depth of 700 yards from the surface, and with a bore-hole put 30 feet into the face of the coal, the pressure was 143 lbs. per square inch; while a bore-hole 50 feet deep, in the 4-ft. seam at Merthyr Vale Colliery, at a depth of 450 yards from the surface, registered 280 lbs. per square inch pressure of gas; it may be further added that these pressures are by no means the maximum ones that have been obtained in different collieries.*

"Blowers" of small dimensions usually follow the face, and as this proceeds, the older ones die out and newer ones take their place. A thin seam of coal overlying the bed worked, is very favourable for supporting this action. By the sinking of the strata, cavities are formed in the measures above the roof, and these are filled with accumulations of gas; a crack is by some means formed, and an outburst of gas results. This action is guarded against in some collieries, by a regular system of putting bore-holes up in the roof, and thereby gradually draining all the gas from the measures. In driving exploring works, large blowers are frequently met with which yield enormous volumes of gas, sometimes for long periods of time, and sometimes for smaller ones. In the former case, the gases are conveyed to the surface through pipes and burnt; while in the latter the district has to be temporarily abandoned until the outburst has exhausted itself.

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* *On Experiments showing the Pressure of Gas in the Solid Coal*, Lindsay Wood, N.E.I. xxx. 163.

CHAPTER III.

SEARCH FOR COAL.

Prospecting.—The preliminary operations in searching for coal in new districts, consist in carefully examining surface indications to determine the nature and position of the beds exposed in the area under examination. A knowledge of geology is indispensable for such work. The banks of streams and cuttings should be closely examined, and all outcrops noted and laid down on a rough sketch-map. Rocks and fossils of Carboniferous age afford the best indication of the probable existence of coal, but it is not absolutely necessary that such should be found at the surface, nor is it certain that, when they are found, coal surely exists beneath. For instance, in this country, the greater part of the Somerset coal-field is covered with rocks of newer formations (Lias and New Red Sandstone); while in the north of France and Belgium, thick deposits of the Cretaceous formation are passed through before reaching the Coal Measures. Perhaps the most remarkable instance of the reversal of strata, is afforded at Drocourt, in the Pas de Calais, where, after sinking through the Cretaceous, they passed, at a depth of 413 feet, into the Devonian; and after sinking in this formation to a depth of 958 feet from the surface, met with very disturbed Coal Measures, and beds of coal, which were worked for a considerable period. The shaft was sunk deeper and deeper, until, at 1886 feet, a fault was reached. On passing through this, the *ordinary* Coal Measures of the district were met with, and are now being worked. The Devonian, and first portion of the Coal Measures met with, had evidently been bent completely over before the Cretaceous was deposited.

Boring.—Even after the examination above referred to, from which the probable existence of minerals may be reasonably inferred, further proofs have to be obtained. If outcrops of actual seams have been found, a great deal can be done by sinking shallow pits or by driving levels. Indications at small depths are, however, seldom conclusive, especially as regards the quality of the coal seams, and the operation of boring is generally resorted to.

Choice of Site.—For proving considerable areas, several holes may be required, the sites of which are determined by the extent, location, and general features of the land to be developed. The preliminary survey decides these general features, but consideration has also to be given to the suitability of the spot for the erection of the drilling apparatus and for carrying on the work.

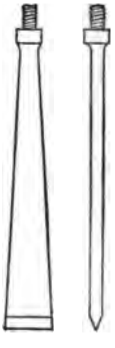
Various Appliances used in Boring.—(*a*) *Bits.*—For shallow holes in soft ground, the borer consists of some heavy instrument of the "scoop" kind, the general form being a cylinder, the cutting edge having a slit up its side like a gimlet. In soft, loose ground, pipes furnished with a cutting edge can be driven down by blows of a heavy wood block, dropped through a considerable height. A second pipe, of smaller diameter, is lowered inside the drive-pipe, and through it, a strong stream of water is forced. This second pipe follows the cutting-shoe, and stirs up the loose material and washes it to the surface.

This method is largely used in America, up to 300 ft. of gravel being easily got through. The pressure of water is sufficient to force up gravel of about ½ in. diameter, but if larger pieces than this are encountered, they must be chopped to pieces.

For harder ground, bits of chisel-shape have to be employed. These are suspended from rods, which are raised up and dropped down, thereby chipping off small quantities of rock. The rods are rotated after every blow, so that the tool drops in a different place each time.

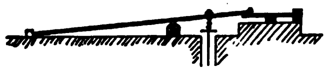
The general form of chisel employed, is that having a straight edge (Fig. 8). The angle enclosed by the cutting edges is variable, depending on the nature of the rock. For hard rocks, a chisel with an acute edge is too likely to break; the angle should not exceed 70°. The size of the chisel should be carefully measured before it is lowered into the hole, as, if it is too wide, it will jam, while if too small, the hole will get too narrow. As with all tools, the chisel was formerly made of wrought iron tipped with steel, but is now universally constructed of steel throughout. For very hard rocks, a V-shaped chisel is sometimes employed. Various other shapes have been tried from time to time, but abandoned, owing to the difficulty of sharpening.

FIG. 8.



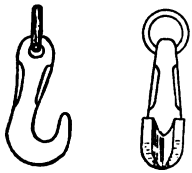
(*b*) *Rods.*—These may be either of wood or iron, the latter being most common. Their usual size is about 1 in. square, and from 28 ft. to 36 ft. long. Shorter pieces for making up lengths are also used. As the hole gets deeper, the thickness of rods has to be increased. The rods are provided with screwed and socket ends. When first used, the rods are not screwed completely together, but only the first three or four threads; when these get worn, more turns are given, but the ends of successive rods must be fixed, but for deeper ones it must be movable. An elaboration of this method consists in the employment of two spring poles. The first is from 60 to 70 feet long, fastened at one end (Fig. 15), and at ⅔ of its length from the fixed point it rests on an upright. To the other end, are fixed two cross-bars which the workmen press down on to a second spring pole, thus producing a dancing movement. Between the upright and the cross beams is attached a hook, from which the boring tools are hung in the usual manner.

FIG. 15.



(*g*) *Frames.*—In order to enable the rods to be raised perpendicularly, a frame of three shear legs is erected at the surface, to which a pulley is attached at the top, one of the shear legs having steps on it so that this may be easily reached. For shallow holes, a windlass supplies motive power, but in larger holes a steam engine and drum is employed. To save labour in unscrewing the rods, it is advisable that the frame should be made as high as possible, so that a long length of rods may be raised at a time. This is done in the following manner:—The stops (*b*, Fig. 11) are opened, and a hook (Figs. 16 and 17), at the end of the rope, is placed beneath a joint in the rods, these being then detached from the end of the lever. The rope is then hoisted up until the limit in height is reached, when the stops are closed beneath the nearest joint, and the rods above that joint unscrewed and removed. This operation is repeated until all are withdrawn. The sludger is then lowered, either by the same rope, or, if the boring is a large one, by a second one passing over another pulley lower down the frame. After clearing out the débris, the rods are replaced by a reversal of these operations. One point must be specially noted: the rods when not in use should never be stood on end, but always suspended.

FIGS. 16 AND 17.



Devices employed to meet Difficulties of Deep Boring.—As the depth of holes increases, a large number of difficulties arise, the greatest one being the weight of the rods themselves. Rods 1 in. square weigh about 1 ton for every 200 yards. In deep holes, not only does this great weight injure the screw joints, alter the structure of the iron, and break the tool which receives the blow, but it sets up excessive vibration in the rods, injures the sides of the hole, and accumulates a mass of broken material above the tool, which often leads to rupture when an attempt is made to withdraw it. To overcome these disadvantages several methods are employed.

(*a*) *Lighter Rods.*—Hollow iron rods were first suggested, the

In deep holes, other guides are inserted in the rods at regular intervals. A common form is that shown by Fig. 12, which readily passes through water. Discs and other shapes have been abandoned, as even where water-ways are left through them, they set up eddies in the water filling the bore-hole, wearing away the sides, and causing them to fall in, if the rock is at all soft.

FIG. 12.

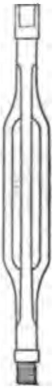
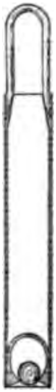


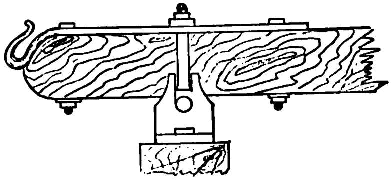
FIG. 13.



(*d*) *Clearing Instruments.*—When a sufficient amount of cutting has been done, the débris which has accumulated at the bottom of the hole is removed by the "sludger" (Fig. 13), which consists of a tube from 4 to 6 feet long, having a valve at the bottom, either of the ball or flap-door type. The removal is usually done with a rope, sometimes a few lengths of rods being added to give weight. When the sludger reaches the bottom, it should be picked up and dropped several times, before raising to the surface. For deep and large bore-holes, a superior class of sludger is employed, having, in addition to the valve at the bottom, a piston working in the barrel portion. When this piston is drawn up, it sucks-in the slime.

(*e*) *Levers.*—The most general way of working the rods in percussive boring, is to attach them to the shorter arm of a lever (Fig. 14), the longer end of which receives an up-and-down motion; as previously mentioned, the rods are suspended by a swivel, and are turned by the bore-master after each blow. Where manual labour is employed, two or more smooth cross-bars are attached to the longer arm of the lever, so that more men are able to work at it. With cross-pieces 8 feet long, six men can work on each side. For deep holes, manual labour is quite out of place, and the long end of the lever is depressed at intervals, either by large teeth on a revolving wheel driven by steam, or, preferably, by directly connecting it with the piston-rod of a cylinder.

FIG. 14.



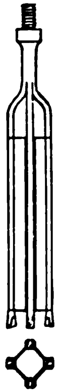
(*f*) *Spring Pole.*—In our coal districts, the vibratory movement is often given to the rods by the use of the spring bar, which consists of a wooden pole having one end fixed to the ground, a fulcrum placed further on, and the rods attached to the other end. The blow is struck by depressing the beam, the rods being raised by the elasticity of it. The lengths of the parts on each side of fulcrum are usually 1 : 3 or 5. For shallow holes, the axis may long length of upper rods follow at a slower speed. When this has descended to the proper point, a slight upward motion, producing pressure on the upper side of the leather disc, causes it to descend with the rod *e* and collar *c*, and so close the fangs.

The above apparatus reduced in a marked manner the breakages of tools and rods, and consequently the cost of boring. It is, however, inapplicable in dry and narrow holes, is somewhat complicated, and causes the water to form streams, whilst the slime from the hole collects on the disc, and prevents it from acting.

Numerous other complicated appliances have been used from time to time, but practically have all given way to the sliding joint invented by Œynhausen. As before, the rods are divided into two lengths, but a sliding joint forms the connection between them. The two lengths *a* and *b* (Figs. 19 and 20) are raised together and also fall together, until the lower part *b*, to which the tool is attached, strikes on the bottom of the hole, when its motion is arrested. The upper part, however, continues its downward movement (the collar sliding over the stationary lower rods), and is gradually brought to rest within the limit of length of the slide by an elastic stop placed beneath the rocking lever at the surface. By this means, the shocks received by the tool and lower rods do not reach the upper part.

Obtaining Cores.—It is of the greatest importance that satisfactory samples of the strata cut through should be obtained. With the tools already described, everything is chopped to small pieces, and it is necessary to examine the contents of the sludger very closely, to determine what material the hole is passing through. In order to obtain more definite results with percussive boring, a tool is put down, consisting of four or five chisels, arranged round a cylinder (Fig. 21), which cuts away an annular space, leaving a central core. A second tool is then lowered down to the bottom of the hole, and a cutting tooth at the base is pressed inwards by means of a spring. This tool is revolved several times, until the greater part of the foundation of the core is cut away, and then by a sharp jerk the whole is detached, and brought carefully to the surface.

FIG. 21.



Special Methods of Boring.—The greatest change which has taken place in percussive boring is that due to suspending the tools by a rope, in place of the rigid bar. To the Chinese, belongs the credit of first employing this means. The shank of the tool consists of a heavy cylinder of iron attached to a rope of bamboo fibres, the torsion of which is sufficient to rotate the tool after each blow. Motion is communicated at the surface by means of a spring pole.

(*a*) *Mather and Platt's system.*—In this method,* the tool is suspended from a flat hempen rope, but the system differs from all others in the measures employed for rotating the tool, and giving it the necessary percussive action. The rope to which the tool is attached (*a*, Fig. 22) passes over a pulley *b*, over the hole, and thence is directed by a guide pulley *c* to the drum of a winding engine worked by steam power. This rope can be clamped at an intermediate point by means of the clutch *d*. The up and down motion is obtained by connecting the pulley *b* to the piston rod of a small vertical cylinder *e*. As the rope is clamped on one side at the point *d*, when the piston moves upwards it carries the tool and rope hanging in the hole, with it, and allows it to fall on the return stroke. As the hole deepens, the rope on the drum is gradually let out. A self-acting valve motion, worked by tappets moved by the piston rod, is employed, and the length of stroke can be varied by altering the position of the tappets. Before the valves can be opened, it is necessary that the piston rod should move; a small quantity of steam is therefore kept continually blowing on to the underside of the piston, through the small port *f*. As the exhaust port is situated a little higher up the cylinder, this really serves an additional purpose, as it interposes a cushion of steam between the piston and bottom of cylinder, preventing any chance of the latter receiving a blow on the return stroke.

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* *Well Boring.* F. Mather, Proc. Inst. Mec. Eng., 1869, p. 278.

FIG. 22.

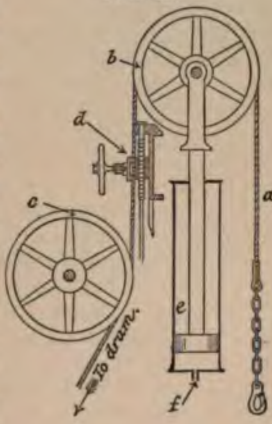
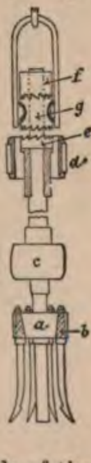


FIG. 23.

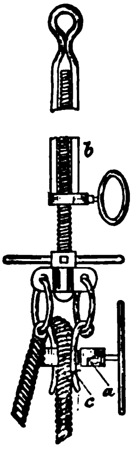


The boring head (Fig. 23) consists of an iron bar about 8 feet long, having a cast-iron boss *a* at the bottom, into which the cutting tools are secured with taper shanks *b*, so as to be firm in working, but easily taken out for sharpening. Two guides are employed to keep the tool perpendicular; one, *c*, being a plain cylinder, the other, *d*, having ribs of saw-tooth form arranged round its circumference. These ribs have a long pitch, and as they bear against the sides of the borehole, assist in turning the tool. Each alternate plate has the ribs inclined in opposite directions, so that one half are acting to turn the bar in rising, and the other half to turn it in the same direction in falling. The definite rotation of the tool is effected by keying two cast-iron collars, *e* and *f*, on to the bar, about 12 inches apart. The top side of the lower collar, and the bottom side of the upper collar, have deep ratchet teeth cut on them. Intermediate between these two, and sliding freely on the bar, is a third collar g, having ratchet teeth cut on both its faces, but those on the upper side are set half a tooth *in advance* of those on the lower side. A wrought-iron hoop is attached to this third collar, through which the bore-head is attached to the hook and shackle shown in Fig. 22. When the tool is dropped and the blow delivered, the teeth of the collar g fall on to those of the bottom collar e, and, through the teeth not being opposite each other, receive half a twist backwards; on commencing to lift again, immediately g engages with f, a further twist backwards of half a tooth takes place, so that the flat rope is actually twisted through the space of one tooth. As soon as the lift takes place, it untwists itself, and so rotates the tool.

The sludger is furnished with a clack at the bottom, and inside is fitted a bucket having an indiarubber valve on the top side.

The boring head can be lowered at a speed of 500 feet per minute, and raised at the rate of 300 feet per minute. The percussive action gives 24 blows per minute, and if this rate be continued in New Red Sandstone or similar strata, about 6 inches will be drilled in 10 minutes, when it becomes necessary to send down the sludger, which is effected at the same speed as the tool, but it only remains down about 2 minutes.

FIG. 24.



(*b*) *American System.*—The development of the oil industry in the United States required rapid boring, and considerable improvements under this head have been effected. The whole operation has been elaborately described by Mr. J. F. Carll.* The success of the operation seems to be due more to the perfection of small details than to any startling novelty. The first thing done is to erect shear legs and fix the wooden conductor box previously described, this being set truly perpendicular, and carried down a few inches into the bed rock to fasten it securely. Should the bed rock lie at a considerable depth beneath the surface, the wooden conductor is replaced by a wrought-iron stand pipe, which is carried down by the method already alluded to. The engine furnishing power is regulated and controlled from the boring stage. The tools are attached to a rope, and an instrument called a "temper screw" (*a*, Fig. 24) connects the rope to the lever through the "stirrup" *b*. The lever receives an oscillating movement from a connecting rod and crank, turned by the band wheel. The length of stroke can be varied by adjusting a collar-pin in any one of several holes placed in the crank at different distances from the centre of its shaft. Separate drums are provided both for winding out the drilling rope and the sludger, these being driven by gearing thrown in and out by clutches. The effective cutting blow of the tools is given by the weight of the chisel, the auger stem, and the lower link of the "jars." The jars is a modification of Œynhausen's slide, arranged in such a manner that the auger stem and bit are given a decided jar on the *up stroke*, so that the bit is loosened, in case it has a tendency to wedge fast in the hole. As the tools rise and fall with the rocking lever, they are constantly rotated by hand, by a short lever inserted in the rings of the temper screw, and as the hole deepens and the screw of the stirrup reaches its limit, the clamps (*c*) of the temper screw are slacked, and a short length of rope payed out.

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* Second Geo. Survey of Pennsylvania, Report I^3.

The withdrawing of tools is carried out by first taking up all the slack rope, then loosing the clamps, throwing the connecting rod out of gear with the band wheel, and lifting up the lever out of the way. The tools are then run up, but are stopped when the bit reaches the level of boring-floor, where it is loosened by large wrenches. The tools are then lifted up clear of the hole, and the rope disconnected from the steam engine, the bit being removed and replaced by a sharp one. While this has being going on, the sand pump, or sludger, has been run up and down once or twice by the friction gear, &c., already described.

The first 60 feet cannot be drilled in the ordinary way just described, this being done by the method called "spudding." The auger stem and bit are attached by the rope socket to a short piece of cable (150 to 160 feet long), the other end being passed over the pulley at the top of the frame, round another wheel, and then a few turns taken round one of the drum shafts. The engine is started, and one of the drillers takes his stand near the drum, with the loose end of the cable in his hands. A slight pull on this, tightens the loose coils on the drum shaft, which is rapidly revolving; the tools are raised, the rope is immediately slackened, and the tools drop in the hole; another slight pull is given, and so on, until sufficient depth is attained to enable the drillers to replace this motion by that of the rocking lever.

This method has been introduced into England, and was used in September 1886 for boring for salt in the neighbourhood of Middlesbrough. Mr. J. Daglish* stated that it proved exceedingly satisfactory, the progress having been remarkably rapid. An *average* rate of progress of 63 feet per day was attained, with a maximum of 5 feet per hour.

(*c*) *Diamond Boring.*—This method differs from the others in the fact, that the tool receives a rapid rotary motion instead of a percussive one. It consists in placing a series of small diamonds around the lower edge of an annular tube (Figs. 25 and 26) called the "crown." This part is composed of soft wrought iron, in which the diamonds are bedded, the edges of the holes being knocked down to keep the stones in position. The common variety of black diamond (bort) is employed, as the cost of the rare gems would be too great. The crown is provided with a series of vertical grooves (*a a*, Fig. 26) round its circumference, to allow water to pass from the centre outwards, and it is made slightly larger in diameter than the main boring-piece, so that the latter can revolve freely in the hole. The main boring-piece consists of a wrought-iron cylinder (Fig. 27) in two pieces, the upper one being open at the top. In the centre of this cylinder is placed a horizontal disc of metal, *a*, which divides it into two portions, and also serves as a connection to which wrought-iron pipes, *b*, are screwed. These pipes are carried to the surface, and are connected by mitre gearing to a steam engine, this giving the rotary motion to the tool. A stream of water under pressure is brought down the centre of these pipes, passes into the lower chamber *c*, on to the bottom of the hole, and escapes by the side of the crown through the waterways already referred to. So long as the water is circulating, the débris is carried away upwards, but as soon as the pressure is taken off, the slime would fall between the sides of the bore-hole and cylinder and jam it. This is the object of making the top piece open. All the falling débris settles in the space *dd′* (Fig 27), around the water delivery pipes.

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* *Presidential Address*, N.E.I. xxxv. 225

FIGS. 25 AND 26.

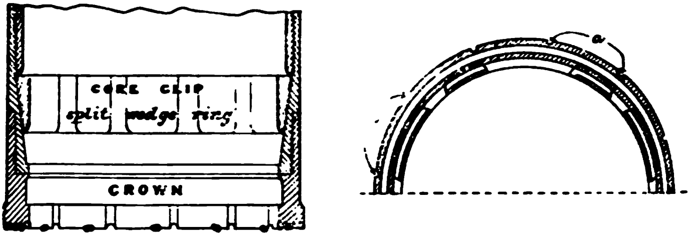
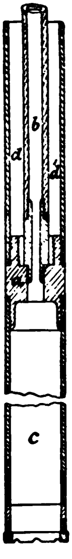


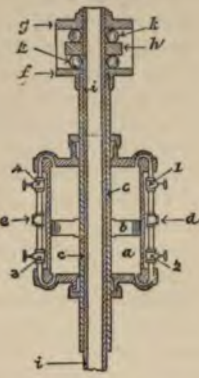
FIG. 27.



A cylindrical core is produced, which is removed in the following manner: A circular *split* band of iron, with vertical ribs, is placed inside the lower portion of the boring tool immediately above the crown (Fig. 25), the surface on which it slides being an inverted cone. In boring, the core readily passes upwards, as it can slip through the split ring, but when the boring tool is raised, the core drags with it the split ring, and gradually forces it on to the smaller diameter of the cone, until the pressure is sufficient to cause the core to break off, and be lifted.

Considerable improvements have taken place in this method of boring during the past few years. The usual practice is now to provide separate machinery for pumping, and rotating and raising the rods, thus dividing and minimising the risk of breakages. The usual method of feeding the drill forward, is to allow the weight of the rods in the hole to do it, but as the pressure exerted would be too much if full weight was put on, part of it is taken off by counterbalancing. A decided improvement on this, is the hydraulic feed of the Sullivan Prospecting Co., which operates as follows: *a* (Fig. 28) is the hydraulic cylinder with its piston *b*, and hollow piston rod *c*. Connection to the force pump is made at the tee *d*, and to the exhaust at *e*. The inlet valves are numbered 1 and 2, and the outlet ones, 3 and 4. When 1 and 3 are open and 2 and 4 closed, the piston moves downwards, but when 2 and 4 are open and 1 and 3 closed, the motion takes place in an upward direction. To the upper end of the piston rod, is screwed the thrust plate *f*, through which pass three stud pins (not shown in illustration) screwed into another thrust plate *g*. Between these, are two sets of ball bearings, one set on each side of the collar *h*, which is fixed to the drive rod *i*. To the opposite end of this drive rod is secured, by means of an ordinary chuck, the wrought-iron pipes to which the drilling cylinder (Fig. 27) is attached, so that the collar *h* transmits the vertical motion of the hydraulic piston to the drilling crown.

FIG. 28.



The advantages of the hydraulic feed are: economy of time, saving of diamonds, and accuracy and safety in operation. The amount of water admitted to, or released from, the hydraulic cylinder can be varied to any degree, by simply adjusting the inlet and outlet valves, and as the feed depends entirely on that amount, it follows that it can be adjusted to the greatest nicety. The hydraulic feed allows the drill to run with slightly slower speed on suddenly entering hard rock, when the attendant can at once give the amount of feed the machine will take without injury to the diamonds. As the water escaping from below the feed piston, is throttled by the outlet valves while feeding down, and led up above the level of the bottom of the piston, it follows that the water cannot escape from the bottom of the cylinder faster than it enters at the top. Hence the lower part of the cylinder is *always full of water*, and in case a cavity is struck, the weight of the drill rods hanging on the piston is supported by this body of water, which is *incompressible*, and *entirely prevents the dropping of the rods*. When a cavity is struck, the hydraulic feed continues downwards as regularly as in drilling through hard rock.

An important detail of this hydraulic drill is the friction bearing (*kk*, Fig. 28); one set of balls sustains the weight of the rods as they hang in the drill chuck, the other set sustain the upward thrust of the rods in drilling. This device reduces to a minimum the amount of work lost in friction, leaving the whole power of the engines to be devoted to drilling.

The great advantage and superiority of the diamond boring system, is the perfect cores obtained from rocks of moderate hardness, which enable an accurate section of the rocks passed through to be easily constructed. In ordinary soft measures (such as coal), owing to the rotary and vibratory action of the bore tube breaking off the core, which falls to the bottom of the hole and becomes ground into mud, the indications afforded by this method in such ground are scarcely better than the slime and débris removed by sludgers in ordinary boring. The breakage of the core has lately been obviated to a considerable extent by the boring of *larger* holes, the larger amount of core inside the crown being better able to stand shocks than the smaller ones of the earlier borings.

A further improvement, by means of which the amount of core extracted has been considerably increased when boring through coal and soft rocks, is described by Mr. James Barrow,* the boring tool being so constructed that a core of the strata can be drawn up intact. This is accomplished by the use of an internal stationary core tube, rivetted to the socket of the ordinary boring tube, an annular space being provided between these two parts for the passage of water. The crown on the boring tube is stepped, to facilitate the cutting of the core, and as the boring tube revolves, the crown penetrates through the strata, and the core enters the inner or stationary tube, which when the bore rods are raised is lifted with them and extracted. When in operation, a constant stream of water is passed down the annular space between the exterior of the core tube and the interior of the boring tube.

This modified tube was employed at Villefranche (Allier) in 1876, and M. Baure † states that the success has been complete, as the greater portion of the cores were extracted in an unbroken condition. Not only did they obtain a complete section of the rocks passed through, but they reduced the breakage and grinding of cores at the bottom of the hole, which so materially increases the power required for turning the tool and augments the amount of débris to be removed.

The modified crown was put to work on 12th Oct. 1876, when the boring had reached 1684.7 feet from the surface, and by the 5th of January 1877, 745.6 feet had been bored, making the total depth from the surface, 2430.3 feet. The length of core extracted was 724.18 feet, or 97.1 per cent., while with the original form of crown, only 39.9 per cent. had been obtained. During the months of Oct. and Nov. 1876, 462.3 feet was bored (from 1609.7 to 2072.0 feet) at an average rate of 11.887 feet per working day, operations being suspended part of this time, while negotiations were being entered into for proceeding deeper with the bore-hole.

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* So. Wales Inst. xii. 42.

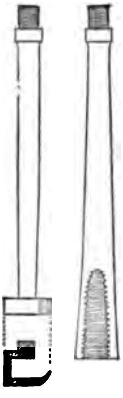
† Soc. Ind. Min. 2ᵉ Série, xiv. 25.

For *very* soft ground the diamond drill is quite useless, and if a hole is proceeding on that system, and such ground is encountered, the crown is removed, and percussive boring tools employed.

Accidents in Boring.—If it were not for accidents, boring would be a comparatively easy and rapid operation. It is in this division that the skill and knowledge of the bore-master is put to the test. The accidents themselves, and the tools employed during such accidents, are so numerous and complicated, that a full description would be quite out of place here, and indeed impossible to give within the limits of the book.

(*a*) *Accidents arising from the Boring Tools themselves.*—The constant vibration and shocks to which the rods are subjected tends to rapid deterioration of the iron, and frequent breakages follow. Often the workmen do not screw the rods properly together, or negligently allow them to drop down into the bottom of the hole during the progress of unscrewing. To lift up the broken part of the rods, a tool called the "crow's foot" (Fig. 29) is employed; it is slipped down the hole, and twisted round until the hooked part catches the rods.

FIGS. 29 AND 30.



If, however, the fracture had taken place some distance above a joint, when the rods were raised the top part would catch the side of the bore-hole, as the crow's foot itself only grips at a joint. In such cases, an instrument called a "bell" is let down. In one form, this is a bell-shaped tool (Fig. 30), with a screw cut on its inside. It is dropped down on to the broken rod, and cuts a screw thread on it. All screwing tools for removing broken rods are cut with their threads right-handed, so as not to disconnect the joints of either the rods to which they are attached, or those that are broken in the hole.

If a piece breaks off the chisel, or any small tool or other hard obstruction drops in the bore-hole, an attempt is made to extract it with an implement resembling a double corkscrew, called a "wadhook

(Fig 31). This is generally successful, but if all attempts to dislodge the obstruction fail, then the only alternative is to chop it to pieces. Mr. Mather, in the paper already referred to, states that it had been found necessary to remove both the heavy boring head and sludger employed in his system of boring by such means. Powerful magnets have also been used with success.

In case of a fracture in the rods (tubes) of the diamond system, an ordinary screw tap is let down and a thread cut inside the broken pipe; in large bore-holes, where the diameter of the hole is large compared with that of the tube, a crooked piece of iron (*a*, Fig. 32) is placed at the lower extremity of the tap, this guiding that piece into the tube in case it should be leaning against the side of the hole.

FIG. 31.

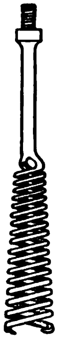


FIG. 32.

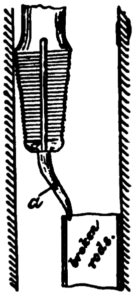
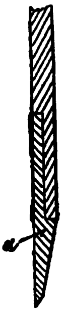


FIG. 33.



(*b*) *Accidents arising out of the Nature of the Ground.*—Unless the strata passed through is of considerable hardness, the constant jarring of the rods, and washing action of the water, soon causes the sides to crumble and fall in over the tool. A very soft bed at any point is a source of considerable danger. In order to prevent serious accidents, it becomes necessary to line or case the sides of the bore-hole.

Lining.—This is done by forcing down wrought-iron tubes in lengths of from 10 to 12 feet, the connections between each length being made "flush"; that is to say, there are not any projecting points. The lower tube is provided with a steel cutting edge (*a*, Fig. 33).

For small holes, the tubes are driven down by dropping a heavy block on them, about 20 to 30 blows a minute being given. A superior method to this is to use two small jacks, which exert pressure equally and gradually, and avoid shocks and risks of bending.

For larger and deeper holes, hydraulic presses are employed having a stroke sufficient to force down one length of tube at a time. A strong framing is built over the hole, and beneath this the presses are secured. Both the hydraulic rams and tubes are carefully guided in a truly vertical direction.

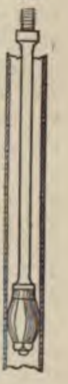
Means of Widening Holes.—When a hole is cased, and boring has to proceed further, it is obvious that the diameter of the hole must be reduced, as the tool has now to pass through the tubes. In order to prevent this, before inserting the first length, the hole is slightly enlarged by a tool called a "reamer," which is very similar to the "bell," except that it is provided with a cutting edge round its circumference. In diamond boring, the reamer consists of a guide the size of the drilled hole, and a face above it, in which diamonds are set, and which cuts away the sides of the hole above the guide.

After the sides have been cased, and boring resumed, it frequently happens that additional casing is required at some point lower down; then either narrow tubes must be sunk through the first set, to reach the dangerous part, or the old casing is removed by one of the methods described below, and the hole rebored large enough to take in the original size of tubes. As a rule, the latter method is not adopted, except when the bore-hole has become so narrow by repeated linings that the first method cannot be employed.

A special tool, introduced by the Diamond Boring Co., is described by Mr. James Barrow.* It consists of an undercutting or expanding crown, a simple arrangement set with diamonds, which is lowered down through the lining tubes, and expanded directly it gets beneath them. In revolving, it cuts away and enlarges the sides of the bore-hole, after each 10, 20, or 30 feet had been bored in advance with the ordinary crown. After this, the lining tubes are lowered to the bottom, and boring resumed in the ordinary way. With such a tool, and the use of hydraulic presses, 800 lineal feet of wrought-iron lining tubes, weighing about 50 tons, have been forced down a bore-hole in one continuous length.

Withdrawal of Casing.—Either when the hole is finished and abandoned, or when inserting tubes of greater diameter, the lining has to be removed. Where the friction is not great, Kind's plug (Fig. 34) can be used. This consists of an oval ball of wood slightly less in diameter than the inside of the tube. It is lowered down on the rods, and a few handfuls of sand or gravel thrown on the top. This causes it to bite, when the tubes can be lifted out.

FIG. 34.



Should the friction be too great to allow the casing to be removed in one length, it is cut through by the tool shown in

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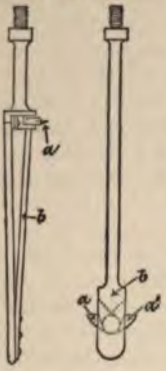
* So. Wales Inst. xi. 318.

Fig. 35. This is provided with a sharp cutting point *a*, pressed against the side of the tubes by a strong spring *b*. On reaching the point where the severance is to be made, the tool is revolved round and round until the lining is cut through, when the upper portion can either be removed by Kind's plug, or by a similar class of tool (Fig. 36) having two spring clips *a a′*, which are pressed inside the shank *b* so long as lowering is taking place, but which spring out and catch beneath the lining, immediately the place cut through is reached. These clips cannot be forced aside in the upward passage, and so the casing is withdrawn.

FIG. 35 AND 36.



Record of Boring.—Exact records should be kept of the work done each day, the strata bored through, and its thickness. Each sludger full of material should be carefully examined, and samples taken and kept for reference. These are best kept in small wooden boxes and labelled. The label should note: place, date, depth, sort of material, and any remarks necessary. Memory should never be relied upon. Neglect of these precautions has resulted in the loss of considerable sums of money, owing to misinformation, at a subsequent date.

Cost of Boring.—This depends in a great measure on the depth to which the hole is carried. A common form of tender is, that the price per foot increases at a certain figure for every stated increase in the depth. As a result, one foot at the bottom of a hole may be more expensive than several feet at the top. In view of this fact, when commencing a boring, a shaft is generally sunk down some distance, and the bore-hole started from the bottom. The low rate is then counted from the shaft bottom, not from the surface, so that, by sinking the pit, a length equal to its depth is cut off from the *bottom* of the bore-hole, which would be at the highest rate. It is stated * that the bore-hole at Sperenberg, 4170 feet deep, made with rigid rods and percussive action, cost 41*s*. per foot; while an average of a series of 37 rope-borings, with depths varying from 80–1300 feet, cost 41*s*. 3*d*. per foot. Mr. T. J. Bewick † states that the first hole at Middlesbrough, bored by Mather and Platt's system, was 1200 feet deep, and cost about £8 6*s*. 8*d*. per foot. It is nearly impossible to compare the several systems, as the conditions may be quite different in each instance. In ordinary strata, the Diamond Drilling Company will contract to put down a hole, commencing at the surface with a diameter of 9 in. at a price of 15*s*. per foot for the first 500 feet, and from 500–1000 feet, 25*s*. per foot, = 20*s*. per foot for 1000 feet; the company providing all labour and tackle (except lining tubes, should such be required), fuel, carriage, and fares; but the employer has to provide, gratis, on the site of the boring, about 10 to 12 gallons of water per minute for engine and other purposes. This price would not vary much even if the hole was of smaller diameter.

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* N.E.I. xxx. 88.

† *Ibid.* xxx. 98.

Mr. H. M. Chance* states that the average cost of drilling a well, by the American rope system, in the oil country in 1878 (including the cost of the plant) for a 1500-feet hole, was £403, or a little over 6*s.* per foot. As prices were at their lowest ebb then, this estimate should be increased about 20 % to make it available for comparison with other methods in 1882; but as the plant would have some value when the operations were concluded, he states that the net cost of a 1500-feet prospecting hole (in 1882) would be £380, or about 5*s.* per foot. At the same time, he points out that the cost of drilling holes by this method in the anthracite regions will be very much greater than that shown by the above figures, because the rocks are much harder, and are inclined at considerable angles from the horizontal. Mr. R. A. S. Redmayne† states that the bore-hole put down by this system at Middlesbrough for salt cost 8*s.* per foot, the depth reached being 1210 feet, and the diameter 8 in.

Surveying Bore-holes.—The great difficulty in boring is to keep the holes truly vertical, and, in spite of all efforts to the contrary, crooked bores are common, especially where the beds are inclined. No rules can be given; the only thing to be done is to exercise the greatest care. Unfortunately, bore-holes, by all the methods, are liable to deviate from the perpendicular, the diamond drill, which was assumed to always bore a perfectly straight hole, being no better than any of the other systems. However, if an accurate survey be made, a crooked hole gives just as valuable information as a straight one.

In the method devised by Mr. E. F. Macgeorge,‡ clear glass phials, filled with a hot solution of gelatine, and each containing in suspension a magnetic needle and a very delicate plumb-bob, are lowered into the bore-hole, and allowed to remain there until the gelatine sets, when they are withdrawn, and by means of a special instrument the angles of the compass and the plumb-bob are noted. Another suggestion § is to lower into the bore-hole glass cylinders containing hydrofluoric acid, which etches a line on the glass. Both these methods are reviewed by Mr. B. H. Brough,‖ who gives a full description of the instruments employed and the way of using them.

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* Second Geo. Sur. Pennsylvania, Report A.C., p. 39.

† Brit. Soc. Min. Stud. x. 102

‡ Engineering, xxxix. 260 (1885).

§ Translation by C. Z. Bunning and J. K. Guthrie, N.E.I. xxix. 61.

‖ *Treatise on Mine Surveying*, 3rd ed. (1891), p. 276.

The uses of Bore-holes in Mines are many and valuable. Every colliery ought to be provided with a set of tools, and men instructed in their use.

(*a*) *Tapping Water.*—A provision of the Coal Mines Regulation Act, 1887, is to the effect that all roads approaching old workings, where there are likely to be dangerous accumulations of water, should be preceded with bore-holes. One bore-hole is usually kept straight ahead for a distance of about 5 or 6 yards, and flank-holes, at an angle of 45° with the centre line of road, are put out for a similar distance on each side. The general practice with the leading hole is to bore in a certain distance, and then remove part of the face, a further length being then bored before any more ground is removed. In this way, the distance from the face to the back of bore-hole is never less than 5 yards. Where water is expected, plugs should be kept in readiness to drive in immediately it is released; or, if the pressure is likely to be great, it is best to bore through a length of pipes fitted with a tap.

(*b*) *Releasing Gas.*—In collieries liable to sudden outbursts of fire-damp, bore-holes are systematically put out of the working places into the layers of strata in which the gas accumulates, in order to drain it out gradually. At Wharncliffe Silkstone, and other collieries where this procedure is adopted, it has met with success.

(*c*) *Proving Faults.*—Bore-holes are of the greatest assistance in determining the amount of throw of faults, and have saved considerable sums of money, which would otherwise have been spent in unprofitable exploratory work. With their aid one can determine the gradient required to drive the roads that will intersect the dislocated seam. Especially is this the case where the hade of the fault is vertical or ill-defined, as they actually prove in such instances, whether it is an upthrow or downthrow.

Owing to the confined space in roadways, the cost of boring is rather high, as much time is wasted in screwing and unscrewing rods. From a number of cases carried out under the author's direction, the cost per foot averaged 4*s.* for distances bored of about 30 feet, with diameter of hole 3 inches, the rate of wages paid to men being 5*s.* 6*d.* per day of eight hours. The cost of boring uphill seems less expensive than downhill, if the weight of boring tackle is counterbalanced, as the disadvantage of clearing out the hole and unscrewing of rods for such purpose is removed.

(*d*) *Steam and Rope-ways.*—The anthracite region of Pennsylvania supplies numerous instances of the employment of bore-holes for steam and rope-ways passing from the surface to the interior of the mine.* At Shenandoah City slope, an 8-in. hole was bored by the method employed in the oil regions, and lined with

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* School of Mines Quarterly, New York, ix. 189.

$5\frac{5}{8}$-in. casing, through which a rope travels, the space between the casing and the rock being filled in with cement. The engines and boilers are on the surface. Another hole, 6 in. diameter, was then bored, and two lines of 2-in. gas-pipe laid in it, the interstices between being filled in with cement. One pipe is used for a speaking-tube and the other for a bell-wire to the engineer at the machinery on the surface. At East Franklin Colliery there are two bore-holes, each 8 in. diameter, cased and cemented, 763 feet deep. These holes are 7 feet apart, and are used to hoist from a double-track underground slope. At Lincoln Colliery, an 8-in. hole is used to convey steam to an underground pump through $4\frac{1}{2}$-in. steam-pipe. As this hole was remarkably dry, it was not cased. At the Clear Spring Colliery, West Pittston, a 6-in. hole was drilled 270 feet, and a line of $4\frac{1}{2}$-in. steam-pipes inserted. This hole was not cased, and, owing to the flow of about $\frac{1}{4}$-in. stream of water down it, condensation was so great that the pressure was lowered from 120 lbs. at surface to 40 lbs. at bottom of hole. Afterwards, the space between the rock and the steam-pipe was cemented, and a 4-in. steam-pipe placed inside the $4\frac{1}{2}$-in. pipe, with the result, that the steam pressure at the bottom of the hole was the same as on the surface.

These holes have also been successfully used in dealing with mine fires, for providing water supplies, and for other purposes connected with mining.

Bibliography.—The following is a list of the more important memoirs dealing with the subject matter of this chapter:

CHES. INST.: *Boring and Boring Machines*, A. H. Stokes. iii. 192.

AMER. INST. M.E.: *Recent Improvements in Diamond Drills*, W. P. Blake, i. 395; *The Diamond Drill for Deep Boring, compared with other systems of Boring*, O. J. Heinrich, ii. 241, and *Supplementary Paper*, iii. 183.

N. E. I.: *Description of an Instrument for ascertaining the Inclination from the Perpendicular of Bore-holes*, C. Z. Bunning and J. K. Guthrie, xxix. 61; *On Diamond Rock Boring*, T. J. Bewick, xxx. 93.

SOC. IND. MIN.: *Notice sur les appareils de Sondage employés par la Société Anonyme de Commentry Fourchambault*, M. Lecacheux, (2^e Série) ix. 337; *Note sur l'outillage employé dans quelques Sondages du Gard*, M. Sarran, (2^e Série) ix. 453; *Sondages des Boubes et de Neuville exécutés à l'aide de la couronne a diamants*, M. Baure, (2^e Série) xiv. 5

SO. WALES INST.: *On the Machinery used in Boring Artesian Wells, and its application to Mining purposes*, W. Mather, iv. 51; *Some particulars of Boring with the Diamond Drill*, A. Bassett, ix. 130; and Hort. Huxham, ix. 201; *Large and Deep Bore-holes with the Diamond Drill*. James Barrow, xi. 315, and xii. 41.

MID. INST.: *On the Diamond Rock-drill*, J. H. Gulland, iii. 254; *A History of Deep Boring or Earth Boring as practised on the Continent*, J. C. Jefferson, v. 105, and vi. 29 and 73.

CHAPTER IV.

BREAKING GROUND.

Contracts.—The greatest proportion of the miner's work, consists in removing and breaking up different varieties of rock, and to do this various special tools are employed. Usually the different qualities of ground are let by contract to men, and it is here that experience is of the greatest use, as only from that is it possible to judge of the value. Hardness, in a mining sense, is different from the same term looked at from a mineralogical standpoint. Ground that is hard and brittle, will often bore better than a softer variety which is tough, because in the former instance, the blows break off small pieces, while in the latter, the chisel has to cut its way. Another point, is the question whether the ground will "shoot" well, that is to say, whether it contains a number of faces, or joints, which easily break away from the surrounding mass under the action of explosives, or, at any rate, allow the material to be so shaken that it is easily removed by wedging. At one of the collieries under the author's charge, numerous intrusions of basaltic rock are met with, and he has adopted a system for judging the value of roading, which is worthy of mention. A sample of every intrusion is kept and labelled, with the price per yard paid for driving through it, and in addition, a microscopical section is cut from the specimen. When other intrusions are met with, a piece is broken from each of them, and a section cut and carefully compared with other pieces and sections of which the price is known. From this comparison, the price to be paid to the workmen is found.

Methods of Hastening Work.—The commonest plan of hastening work, and one that gives good results, is to pay the men a bonus for every extra yard they drive over a certain stipulated amount. So far as working is concerned, perhaps, the cheapest way is to only work one shift, for, as a rule, the night shift leave work behind for the day men to do. If different shifts of men are employed, the best way is to measure up the amount each shift does, and pay them on it, as by this means each set of men know that they will receive the money for all the work they do, and consequently work harder. Where rapidity is the main object, six-hour shifts are adopted, with one workman always remaining to, and starting from, the middle of a shift. This one does all odd work, fetching tools, &c.; the regular workmen are then able to keep constantly at the face.

TOOLS USED.—**Shovels** are principally used for removing broken débris, and always have pointed noses, to enable them to get past the larger pieces of loose stuff. The length of handle varies; commonly it is about 30 in., this being set at an angle of from 140° to 160° with the surface of plate, which varies from 8 to 16 in. across. In some districts, baskets are used for loading in preference to shovels, the coal being raked into them. They are largely employed in the South Staffordshire coal-field, and are made of wicker-work for the working places, and of iron for gate-roads, the reason of this being, that the former are practically noiseless. With them, a man certainly loads more stuff than with a shovel, especially where the ground is uneven, as in such cases the shovel catches on projections. Their application is limited to thick seams.

Picks.—These vary much in shape for different uses and different qualities of ground. For holing purposes, where the blow is struck in a horizontal direction, the weight is small, generally about 3 lbs., with a head 15 in. long, and a helve from 24 to 33 in. The head will be slightly curved for holing along a straight long-wall face, as the miner naturally swings his pick in a curve, and the blow is then delivered in the direction the instrument is moved. If, however, the miner is under-cutting in a narrow road, and working in the corners against the "fast," the curved head cannot be employed, as the curved portion would catch against the side before the point entered. For cutting coal or breaking rock, the shape of the shank, or stem, is usually square in section, tapered to a point; while for dressing rocks when sinking, a chisel-shaped edge is employed. For coal work, the shank tapers uniformly from the eye to the point; but for stone work, the point tapers suddenly, like the sharpening of a pencil. The head part is fitted into a wooden stem, called the helve, upon which the greater strain of the work is thrown; so, to prevent rupture of the wood the eye should be made as broad and long as possible, and the two side cheeks carried down the helve a good distance. On the other hand, for under-cutting, where the tool works in a narrow slit, the eye must be made as slim as possible; if not, the pick-head cannot be turned sufficiently to enable the point to catch the sides of the cut. Helves are generally made of good straight-grained ash, nicely rounded to fit the hands of the miner.

American hickory helves are becoming largely employed, the only objection raised against them being that they are rather too springy, and jar the hands in delivering a blow. This objection, probably, arises more from prejudice than anything else.

A pick worthy of mention is that known as the *Rivelaine*, employed by the French and Belgian miners for holing in thin inclined seams. It is made of flat steel, about $\frac{1}{8}$ in. thick, and the helve is from 3 ft. 6 in. to 4 ft. long (Fig. 37), so that the miner does not have to get his arms under the face. A very narrow slit is made, and waste is reduced to a minimum.

In the day, a workman spoils the points of several picks, which he has to bring to the surface to get sharpened. The labour of doing this is considerable, and numerous devices have been brought out with a view of lightening it. The oldest consists in employing loose points, held in position by a screw, but the idea is a failure, owing to the difficulty of keeping them tight and firm, which is only possible when they are new. A better plan is that of the Hardy Pick Co., which consists in making the head loose, and either employing a tapering helve, getting slightly broader towards the top, and threading the head over the end of the handle, and allowing it to slide down into its proper position (Fig. 38), or by recessing the head of the pick, and fitting it into a rectangular iron collar at the top of the helve, and securing it in position by means of a sliding wedge (Fig. 39). Originally a double wedge was employed, with a view of making a more secure joint, and allowing for wear; but experience has shown that no necessity exists for this, and the single wedge pattern is most in favour.

FIG. 37.

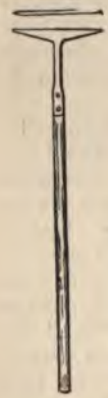


FIG. 38.

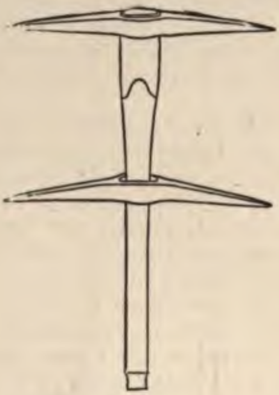
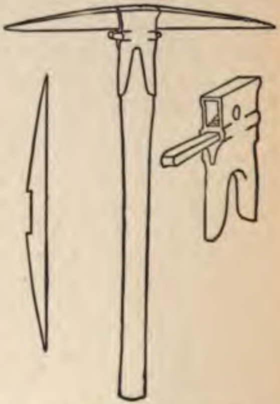


FIG. 39.



The tendency at the present day is to construct picks entirely of steel, instead of wrought iron with steel points. Without repeating this remark again, it may be taken as true with regard to every other class of mining tools. The texture of steel is such, that it transmits a blow better than softer iron, and as it is stronger, the weight of the tool is less; consequently the point receives the impact better. Then again, the wearing capacity of steel tools is very much greater, and repairs are consequently less.

Dressers.—For breaking up all large pieces of coal and rock, a tool shown in Fig. 40 is used. The direction of the blow being downwards, it is made very much heavier than an ordinary pick. One side of the head forms a curved pick, and the other a hammer. The helve is not straight, like that of a pick, but curved, and as it is largely used for wrenching purposes, two strengthening side strips, *a a*, pass from the eye up the helve.

FIG. 40.

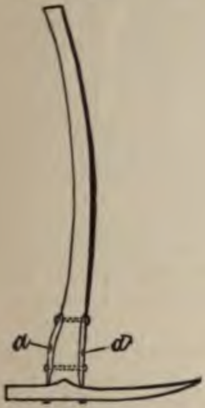


FIG. 41.

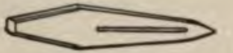
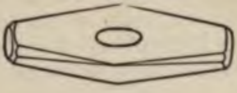


FIG. 42.



Wedges.—These are most useful tools for breaking up hard rocks, and getting down pieces shaken by shots. Their shapes are few, but harder rocks require smaller wedges than softer ground, as in the latter case a small tool would only push its way into the rock, and be buried in it. The general shape is shown in Fig. 41. The striking end is made small, so that the blow is delivered in the centre. For soft, cloddy varieties of ground, the penetrating end is made somewhat of a chisel shape, as this tends to split it very well; but with harder varieties of rock, small dumpy wedges are adopted, gradually tapering towards the extremity, and suddenly sharpened to a point.

Hammers.—The common form (Fig. 42) consists of an eye and two stems, tapered down to form the striking faces, which are slightly convex, and have their edges rounded or chamfered off, so that the hammer glances off the object struck when the blow is misdirected, and prevents injury to the hand of the man holding the drill. The only difference between hammers and sledges is, that the latter are heavier, and the blow is delivered with both hands. For wedge-driving, long, tapering heads are adopted, so that they may follow the wedge right into the mineral; while for drilling, shorter heads are used, as in them the material is well concentrated, and the blow takes greater effect.

Drills.—For the present, it is proposed to treat only of those drills worked by hand. These may be divided into percussive and rotary borers. The former are either worked by the miner grasping the tool, and giving it a reciprocating action, or one end of the tool is struck with a hammer. The latter may be subdivided into two classes, one of which wears the mineral away (diamond), while the other crushes the rocks, and reduces them to small fragments, this being done either by a screw working through a nut, or by hydraulic pressure (Brandt's).

Comparing percussive borers with rotary ones, the useful effect of the force expended is decidedly in favour of the latter. In hand tools of the former class, about half the time is expended in bringing back the hammer into place to deliver a fresh blow, and, in addition, a considerable amount of power is wasted in the inertia and rigidity of the tools. Ill-directed blows are also a source of loss. Even with machine drills, the same objections hold good, but here the undoubted advantage is the obtaining of deep holes. In harder rocks, percussive action is necessary, but in softer materials, easily disintegrated, the débris tends to choke the hole, jam the drill, and cushion the blow. As the generality of coal-measure rocks can be penetrated by rotary drills, it seems preferable to use that class.

Percussive Hand-tools.—For soft rock, the tool employed is called a "jumper," the hole made being a large one. It consists of a bar of iron, from 5 to 6 ft. long, having a broad curved bit at one end. This bar is grasped by the miner in both hands, and a reciprocating motion given to it, and at the same time it is slightly turned between each blow, so that the cutting edge strikes in a fresh place each time.

This method is only applicable in soft varieties of rock, and is soon replaced by the system in which the tool is struck a blow with a hammer. Here two divisions of labour, called single and double hand sets, may be noticed. In the former, a man holds the drill in one hand and delivers blows with the other; in the latter, one man holds and turns the drill, while the striking is done by another man, and sometimes, in very hard ground, by two men. In single-hand tools, small drills are employed, and the power expended is more effectively applied than in double-hand sets using larger tools, as in the latter case one man is solely employed turning the drill. The bits too, in small drills, stand better than large ones, which is probably accounted for by the more uniform temper. The blows delivered with the small drills are more rapid and light, this being advantageous in a hard siliceous rock, as there is more tendency to break it off in small pieces, requiring the expenditure of less power, and there is also less liability to injure the tools. The drills of both classes are composed of a stem (generally of octagonal section), a striking face, and a bit. The end which receives the blow, is made smaller in diameter than the stem, so that the blow strikes dead in the centre. The remarks previously made about constructing picks of steel apply more especially here. Steel being so much stronger than iron, the stem can be materially decreased, and the mass through which the blow has to be delivered is correspondingly reduced, with the result, that the power expended is more effectively employed.

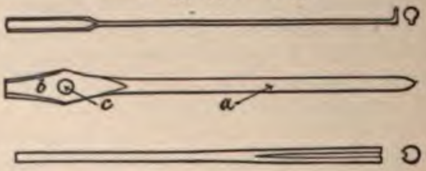
The edge of the chisel is generally curved to a certain extent, more so for softer rocks than for harder ones. The edges also are less acute for the latter class. In boring a hole of any depth, the first tool used is shorter than the following ones, and the breadth of the bit of each succeeding drill is less than the one before, so that the tool can clear itself and follow freely in the hole. The great thing in hand-drilling is to properly turn the drill, so that the hole is round; otherwise it is impossible to bore deep holes, and the cartridges employed for blasting do not fit properly, leaving spaces in which the gas expands when the shots are fired, and the useful effect is lessened. In the Cleveland iron mines, triangular holes are bored and loose powder employed, it being claimed that such form is specially advantageous in the deposits of that district; but machine drills, boring round holes, are making great headway there.

There is a special art in sharpening and tempering tools. The blacksmith must be experienced in the different qualities of ground. The only objection raised against steel tools is, that the points sometimes break off with the first blow or two after being put to work. The fault in such cases does not so much lie with the steel as with the smith, as the explanation of the sudden fracture is that, in hardening and tempering the point, the tool is plunged into cold water whilst a portion of it is yet at a red heat, the consequence being that the steel is made as brittle as glass. In sharpening, in no case should the tool be heated to more than a blood colour, and no further up the stem than is absolutely necessary, and it should then be hammered lightly and quickly until quite black. After being sharpened, it is perhaps best to allow the tool to cool down before it is tempered; but such is not absolutely necessary, so long as it is not made red-hot too far from the point.

In hardening, the tool should not be heated further up than 1 in. from the point, and it is then dipped into cold water for about $\frac{3}{4}$ in., leaving $\frac{1}{4}$ in. still at red heat. The edges of the tool will then be filed, so that the polished surface of the metal is exposed to the atmosphere, when the heat remaining in the top part gradually passes towards the thin edge, and various colours successively appear on its surface, these indicating the temperature the metal has attained and the degree of hardness still remaining in the steel; when the desired colour appears, the article is plunged into water, completely cooled, and retains the temper, as it is called. The colours appearing on the steel during the tempering process vary from a faint yellow, through brown and purple, to a full blue colour, the former giving the very hardest temper, while in the latter the metal is so far softened as to permit of a little bending in small articles before any fracture takes place. The experience of the smith is the only guide as to which hardness the tool should be tempered. It must be harder than the mineral to be attacked, but should also be soft and tough enough not to be brittle. There is no advantage in having a very hard, brittle tool to cut soft rock.

Scrapers.—In percussive boring, the débris produced at the bottom of the hole is cleaned out from time to time by the use of a tool called a scraper, which generally consists of a rod of copper, with a circular disc at right angles to it at one end, and a semi-circular groove, like a cheese-scoop, at the other (Fig 43). Unless the disc end is considerably less in diameter than the hole, the powdered mineral is pushed right to the back, and prevents the bit getting at the rock when it is re-inserted. To dilute the sludge, and prevent the tool from sticking and getting hot, water is introduced in downhill holes; a little ring of straw, or a piece of leather with a hole in it, through which the tool passes, is put over the hole to prevent the sludge spurting out.

FIGS. 43, 44 AND 45.

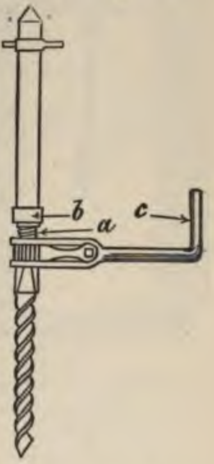


Tamping or Ramming.—When a hole has reached its required depth, the blasting charge is inserted and rammed; that is to say, some material is placed over it to prevent the escape of the gases through the front of the hole, and so confine them at the back of it, their only escape being to blow out the rock. In preparing the hole, it is carefully scraped out for the last time, and if water has been used during boring, it is dried by connecting to the scraper a small wisp of hay, or rag, which forms a sort of plug, and sucks up moisture; or, if the hole is very wet, the claying or "bulling" iron is employed. This consists of a stem of wood (*a*, Fig. 44) and an iron head (*b*) through which a hole (*c*) passes. A lump of clay is inserted into the bottom of the bore-hole, and the stump of the claying iron driven in, forcing the clay into the interstices of the rock, and actually forming a lining round the hole. The bulling iron is lifted out by passing a cross-bar through the hole *c*. The charge and tamping are then put in, the latter in small quantities at a time, each quantity being successively rammed with the tamping-rod, which consists of a bar having at one end a flat face, while the other terminates in a cone having a groove cut in it (Fig. 45), to allow the means for lighting the shot to lie against the side of the bore-hole. This may be either a needle, or pricker where straws are used, or fuse, or wires if electricity is the agent. The farther the tamping is from the charge, the harder it is stemmed. In strong rocks blows are given to the end of the rammer by a hammer.

Hand Machine Drills.—The general type of these consists of a screwed spindle working through a nut, with a socket for the boring tool at one end, having a square on it for the ratchet-handle which communicates power.

The tool commonly employed (Fig. 46) consists of a screw-spindle *a*, working through the nut collar *b*. The boring-bit is of the ordinary auger form, with a **V** point. The screw is revolved and pressed gradually against the rock by turning the ratchet-handle *c*, small pieces are broken off, and the hole is bored. When the advance has reached the length of the drill, it is worked back into its sheath again, and a longer one inserted. With an ordinary nut arrangement, as many revolutions have to be made with the screw to replace it in its sheath, as took place during boring. To prevent this waste of time, a split-nut, having lugs on each half tapped with right- and left-hand threads, is adopted by the Hardy Pick Co. These lugs are connected by a screw, cut with a right-hand thread at one end and a left-hand thread at the other, and can therefore either be brought in contact with, or disengaged from, the main propelling screw. Consequently the drill and screw can be withdrawn without being wound back.

FIG. 46.



With this type of drill, a tree or prop has to be set near the face, to support one end of the machine. To prevent loss of time, many machines are supplied with a stand, whose length is adjustable, as it is formed of two pieces which can slide upon each other, and be clamped together, the final adjustment being made by an ordinary lengthening screw at the bottom.

In the Elliott machine (Fig. 47) the nut is replaced by a worm-wheel *a*, in the teeth of which, a square-threaded feed-screw *c*, of $\frac{1}{2}$-in. pitch, takes its bearing. This wheel is carried in a ring, having a hinged joint at one side, and a screw clamp *b* on the other, so that more or less friction can be set up between the screw and the worm-wheel. The feed is thus automatic, and the extent is regulated by the tightness, or otherwise, with which the ring is screwed up. If the resistance is excessive, the wheel slips round to a certain extent, and reduces the full advance of the drill, which may vary from $\frac{1}{2}$ in. per revolution to nothing.

If the clamping screw *b* is slacked, the drill can at once be withdrawn without being wound back.

When boring near the sides or roof, the crank-handle cannot be completely rotated, but has to be worked backwards and forwards, and a ratchet employed, thus all the time devoted to one half the motion is lost. To remove this disadvantage, the crank-handle is not connected directly to the screw, but through the intervention of bevel gearing. Bornét's* machine is so fitted, and in addition, the nut in which the feed screw works is seated in a spring box, so that with an increase in pressure, when working in hard strata, the feed is equal to the pitch of the screw, less the amount of compression of the springs. When these are fully compressed, the nut slips out of its bearings, and revolves with the screw, the feed being then governed solely by the spring pressure, until the resistance decreases, and the nut again occupies its seat.

FIG. 47.

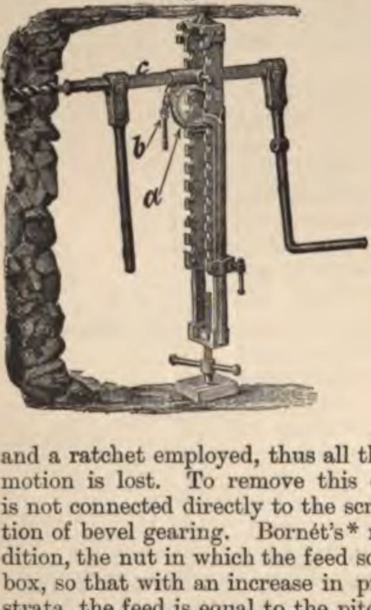
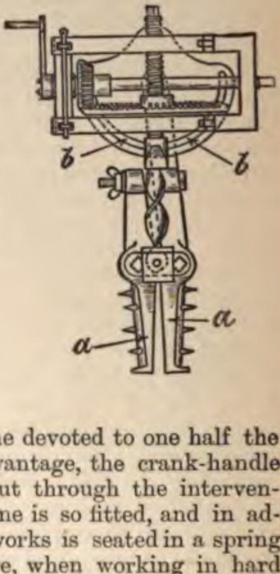


FIG. 48.



In thick seams, ordinary stands cannot be employed. In the anthracite mines of America they are replaced by a clamping device, shown in Fig. 48, attached to the Howell† drill, one of the best known in that coal-field. To fix the machine, a hole, 3 or 4 in. diam., is first cut into the face, and the clamping-bar *a*, which is supplied with a number of spikes, is firmly wedged in it. The illustration to a great extent explains this. The auger bit is rotated by bevel wheels, geared down from 1 : 3 to 6. A point worthy of attention, is that two or three holes can be bored from one position, owing to the sector arm *b* allowing movement either to the right or left.

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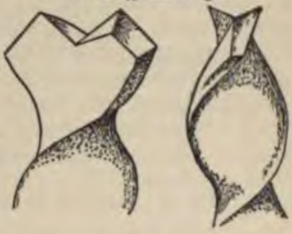
* N.E.I. xxxvii. 117.

† Report A.C. Second Geo. Survey Penn., p. 172

The merits of a drill depend upon its weight, the facility with which it may be set and used in different positions, and the wearing capacity of the machine itself. The rate of boring depends entirely on the form of the cutting tool and the quality of the steel, because, unless the latter is suitable metal, it is no use making it of a suitable form, as that form is soon lost by rapid wear. A great deal also depends upon the men. Unless a certain amount of skill is shown in setting the machine, and properly clamping it in position, as much time is occupied in drilling holes in ordinary varieties of rock as if they were put in by hand.

FIGS. 49 AND 50.



The most suitable shape of the points of the twisted augers for drilling ordinary rock-binds and coal, is shown in Figs. 49 and 50. This form penetrates with greater speed and less labour than any other pattern, and is easy to repair. The piece cut out of the centre, should be a little more than one-third of the width of the point, and of a broad V shape, in order to keep the two outside portions as strong as possible. These should be kept as thick and stiff as the section of the steel will admit. The cutting point should be carefully kept sharp, with a good clearance left at the back. As a rule, the greater the opening in the middle, the more rapid is the penetration, especially in coal, shale, and soft sandstone; but the size of the V opening is governed by the hardness and strength of the rock to be bored. When great pressure is necessary, the opening at the top of the V should be narrow.

The best results are obtained in tempering, by heating one inch of the points to a blood-red, and then plunging them into coal-tar, as the cutting edge is made extremely hard, the points gradually becoming softer as the thickness of steel increases. Drills so treated, can be re-sharpened once or twice on a grindstone, until it becomes necessary to put them in the fire again to enlarge the points.

To show the advantage of using these drills, the following example is given :—At a colliery under the author's charge, a road was driven for 61 yards, crossing the measures over a fault.

The section of the road was 6 ft. wide at the bottom, 5 ft. at the top, 5 ft. high, and it was driven at a down gradient of 2½ in. to the yard. Time occupied, 5 weeks; rate of progress, 12 yards per week. The cost was: labour, £47 10*s.*; powder and fuse, £11 18*s.* 9*d.*; total, £59 8*s.* 9*d.* The total cost per yard run was 19.488*s.*, equal to 6.386*s.* per cubic yard; and the cost of explosives per yard run was 3.914*s.* The hardness of the measures varied considerably. A small portion could be worked with the pick, but other parts consisted of a hard, gritty sandstone, nearly too hard for the drill. Very little timbering was required, so this did not interfere much. Ventilating pipes and rails had to be laid. The road might be considered a very fair sample of a cross-cut in the Coal Measures. Similar work in another part of the pit, without the aid of a drill, cost £2 a lineal yard.

TRANSMISSION OF POWER.—In considering the question of transmitting power to the machines used in breaking ground, choice is limited to compressed air and electricity; the other means of steam and wire ropes are inapplicable. Steam is, to a certain extent, out of place in a mine, although, under certain exceptional conditions, it is employed, and gives good results; but its use in confined spaces, where either coal-cutting is in progress or rock-drills are being worked, is quite out of the question.

Compressed Air.—Air may be considered a perfect gas, and obeys the laws relating to such a body. These are:

(1) That if the temperature be kept constant, the volume varies *inversely* as the pressure; if for example, the pressure is doubled, the volume will be reduced to one-half.

(2) If the volume be kept constant, pressure varies *directly* as the temperature reckoned from the absolute zero (-273° C. = -459° F.). Thus double temperature gives double pressure.

(3) If the pressure remains constant, the volume varies *directly* as the temperature reckoned from the absolute zero. Thus if the temperature is doubled the volume is doubled.

If the above laws are clearly understood, it will be at once seen that great losses must occur in compressing air. When the volume in the cylinder is reduced by the piston, a considerable rise in temperature takes place, which can only be produced by an expenditure of power, heat being simply work in another form. If the compressed air were used immediately at the point where it was generated, no loss would take place. This, however, is never done; the heat produced by compression is lost in the transmission-pipes, and all the power which produced it is lost also.

The increase of temperature during compression, expands the air in the cylinder and increases its pressure, so that the piston is met both by the natural resistance of the air to compression, and by the increased resistance due to expansion by heat. Another loss through this heating is that, at the moment of discharge the air bears the pressure it should do, but as it cools the pressure falls. It has been noted that, in an ordinary compressor, the air was compressed to four atmospheres after the piston had travelled $\frac{3}{5}$ths instead of $\frac{3}{4}$ths of its stroke (see first law above), the compressed air occupying $\frac{2}{5}$ths instead of $\frac{1}{4}$th of the space in the cylinder.

A third loss is due to the fact that the sides of the cylinder become heated, and the air on entry is expanded, so that when the piston commences its stroke, a smaller mass or weight of air is in the cylinder, but the increase of pressure due to the temperature makes the pressure normal.

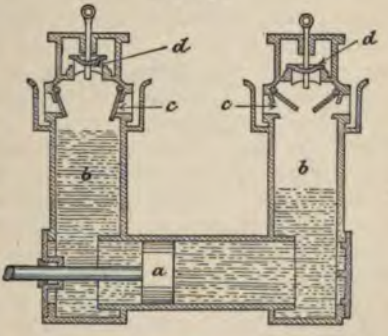
From these considerations it follows that, to secure good results, there should be (1) thorough cooling during compression, and (2) the air on introduction should have as low an initial temperature as possible.

Air Compressors.—Two systems are in use by which the heat produced during compression is absorbed. In one, water is not admitted into the cylinder, while it is in the other. The former are called "dry" and the latter "wet" compressors.

In dry compressors, air is cooled during compression by the use of a water-jacket on the compression cylinder, but at the best the action of this is very imperfect, as the area of surface exposed to the cooling action is small, compared with the volume of air compressed, so that only a small portion of the confined air can come into contact with the inner surface of the cylinder. In addition, air parts with its heat to a metal cylinder very slowly, and, with a compressor working at moderate speed, there is not time between the inlet and discharge to effect sufficient reduction in the temperature.

Wet compressors may be subdivided into two classes—(*a*) those where the air is compressed by a piston of water, (*b*) where a fine spray of water is injected into the cylinder during compression.

FIG. 51.



The former type, the design of which is due to Sommeiller, is illustrated in Fig. 51, and consists of a piston *a*, moving horizontally in a cast-iron cylinder kept full of water. From the extremities of this cylinder spring two vertical cylinders *b b*, closed at their upper ends by covers bolted on. The in-take air is admitted through rectangular openings *c c*, in the sides of the vertical cylinders, the suction-valve being of leather, while discharge takes place through a conical brass valve *d*, situated in the top. The reciprocating movement of the piston causes the water to rise on one side and fall on the other. A partial vacuum is formed above the falling water, which causes the admission-valve to open and the unoccupied spaces to be filled with air; while on the return stroke the water is driven back, and the air with it, until compression in the cylinder is equal to the pressure in the receiver, and then the delivery-valve opens.

These compressors have been largely employed on the Continent, the idea being that, if the air during compression was in contact with water, all heat would be absorbed. Such, however, is not the case. The air is only exposed to water on one side; a thin film of this soon gets hot, and, water being a bad conductor of heat, little cooling during compression takes place. As, however, a certain quantity of water is carried over into the delivery-pipes at each stroke, the air is cooled before it gets to the receiver; but to be of any economical good, cooling should take place during compression. Indeed, it has been found that, to get good results, spray injection has to be introduced near to the outlet-valve.

Compressors of this class resemble pumps, and must work at slow velocities. As a large body of water has to be set in motion and stopped at each stroke, considerable friction is caused, and the machine subjected to severe shocks. It must, therefore, be made very strong, and to produce the same quantity of air as a high-speed compressor, must be considerably larger, and take more power to drive.

The actual position of affairs seems, therefore, to be that, by the assistance of a water piston and spray injection, a certain economy in compression is gained, while this advantage is neutralised by the extra power required to drive the machine. In addition, there is the difference between first cost and cost of maintenance in the two systems. It is impossible either to purchase large engines, or to keep them working, at the same cost as smaller ones.

The second division of wet compressors is that in which water is injected directly into the cylinder. This answers well in keeping down the temperature, provided that the water is in the form of fine spray, that it meets the piston during compression, and that it is in thorough contact with the air. A further economy results from the fact, that the power required to compress moist air is less than that required for dry air. The injected water also fills clearance spaces, and prevents loss from this cause. The absence of these in a compressor cylinder is a point of high importance. No spaces should exist between the piston and the cylinder cover at the termination of the stroke, because such spaces are filled with air at high pressure, and, on the retreat of the piston, this air expands and fills the cylinder, no free air entering until the pressure is reduced to that of the atmosphere.

It is, however, believed that the cooling results obtained by e use of a spray of water are deceptive, as they take place incipally after the air is completely compressed.

The objection to the injection system is the wear of the cylinder d piston, caused by the fact that water is not only a bad lubri- nt itself, but its presence in the cylinder prevents oil, or grease, tting to the working parts, as it floats on the top of the water. he situation is bad when clean fresh water is used, but much orse when, as is often the case, it is necessary to employ acid ater or water containing grit or sediment. Another objection , that the compressed air produced contains a considerable nount of moisture, and that when used the exhaust ports of the otors become clogged up by the formation of ice. By a proper rangement of reservoirs, or draining tanks, most of the moisture the air can be removed before it is used in the motors.

The difficulty in getting rid of the heat produced by com- ression has hitherto prevented the use of even moderately high ressures, but the means adopted at the Paris installation * have ercome this. The air is compressed in two or more stages, and oroughly cooled between them. This intermediate cooling is sily and thoroughly effected, the air being taken through tubular ssels which present any amount of cooling surface that may be quired.

The general type of modern air compressors, consists of a pair of gines having the air cylinder arranged, tandem fashion, behind e steam cylinder. With a single engine and air cylinder ranged in a straight line, it is impossible to construct an onomical machine, because the greatest work in the air cylinder s to be done at the end of the stroke. At the beginning of the roke, when the steam has full pressure, the air cylinder contains r at atmospheric pressure, and offers no resistance, but at the d of the stroke, when the pressure in the steam cylinder would low (if expansion were used), the resistance in the air cylinder at its maximum. All sorts of arrangements have been designed equalise the power and resistance, but have given way to the raight line pair type, with cranks set at right angles. Expansive orking can then be used, as one steam cylinder is always exert- g its maximum power at the moment when the air cylinder of e other engine is finishing its stroke.

This explains the seeming paradox, how steam, say at 50 lbs., n compress air to 70 lbs., where both cylinders have the same ameter and stroke. When it is remembered, that at the commence- ent of the stroke the pressure in the air cylinder is nothing, at for three-fourths of the stroke it is considerably below lbs., and that only at the moment of discharge does it reach lbs., the explanation is self-evident.

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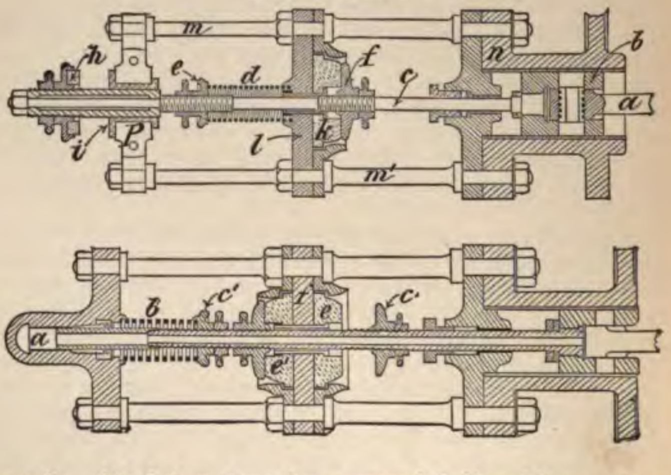
* Inst. C.E. cv. 180.

Various Valves on Air Compressors:

Walker's Valves.—The inlet valve is connected by a link (a, Fig. 52), and piston b, with a controlling spindle c, these reciprocating with the movement of the valve. When the piston retreats, suction opens the valve, which is prevented from going too far by the spring d, which becomes compressed. Immediately the piston starts to return, the valve is closed by the spring, and prevented from being violently dashed on to its seat by the collar f, which moves with the spindle, coming into contact with the india-rubber buffer k, carried on a fixed abutment l, suspended by two bars m, m', attached to the cylinder cover n. Messrs. Walker's experience has shown that it is also desirable to buffer the valve on its in-stroke, this being done by a second india-rubber washer h, striking against another fixed abutment i. It will be noticed from the drawing, that the tension of the spring, and the position of the stops, can be varied, if desired, by a nut and lock-nut arrangement, e and f.

FIGS. 52 AND 53.



The outlet valve (Fig. 53) is balanced by making a portion of the spindle passing through the stuffing-box hollow, the outer end passing into a small cylinder a, into which air is admitted at the same pressure as in the receiver. The valve is prevented from opening too rapidly by the spring b, and is buffered on its in-stroke and out-stroke by stops, c, c', arranged to engage the india-rubber blocks, e, e' (carried by a fixed cross-bar f), just prior to the termination of the valve's travel.

The india-rubber blocks are annular in form, but somewhat of a T-shape in cross section, the faces of the annulus being widened out to leave a projecting flange at the inner and outer periphery. With this shape, it has been found that the life of the blocks is considerably increased.

Sturgeon's Valve.—The feature of Sturgeon's Air Compressor consists of a stuffing-box inlet valve, which is opened by the piston-rod at the commencement of its stroke, this doing away with the necessity of forming a vacuum, in order to cause the valve to open. A complete cylinder, full of air at atmospheric pressure, is taken in at each stroke, and immediately the piston starts to return, the valve shuts. In Fig. 54, *i* is the inlet valve attached to the stuffing-box of the piston-rod. By means of the nuts, *a*, *a*, sufficient grip can be obtained to ensure the valve opening on the forward and backward strokes of the piston. The stops, *b*, *b*, screwed to the valve, limit its travel in one direction, while its flange portion performs the same office in the other. The piston is recessed to fit over the valve at the termination of each stroke, and reduce clearance to a minimum. The outlet valves, *o*, *o*, are usually eight in number and can be taken out

FIG. 54.

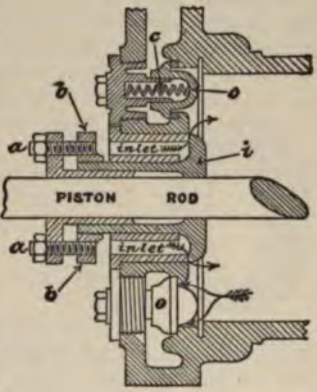
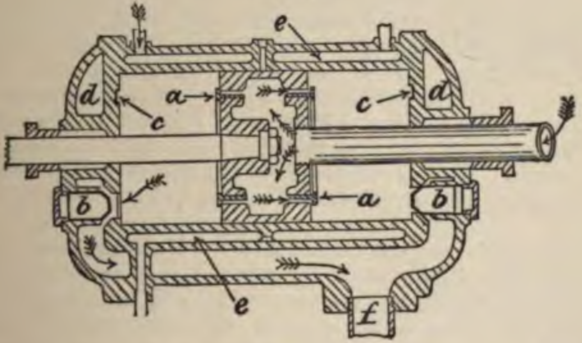


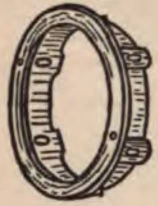
FIG. 55.



separately for repairs, or removed by unscrewing. A spiral spring *c* in each one, serves to bring it back sharply on to its seat. The arrows show the direction of the air both from the inlet and delivery-valves.

Ingersoll-Sergeant Valve.[*]—This consists of two annular valves (*a*, Fig. 55), placed in a hollow piston of a double-acting air-cylinder, free air being admitted through a hollow tail-rod attached to the piston. The valves do not require the aid of springs or other connections, but are opened and closed at the proper moment by their own inertia. The arrows show the direction of the intake and delivery; the outlet valves are shown at *b*. To reduce clearance, small recesses, *c*, are turned in the cylinder covers, into which the inlet valve fits at the termination of the stroke. As there are no inlet valves in the cylinder covers, water-jackets, *d*, *d*, are provided at each end, as well as around the sides, *e*, *e*. The air passes into the receiver through *f*. A perspective view of the valve is shown in Fig. 56.

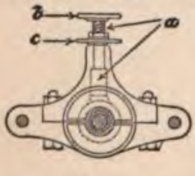
FIG. 56.



Means to prevent "Dancing" of Valves.—In the ordinary form of valves to which a spring is connected, vibratory motion is set up, because the air tries to pull the valve open and the spring to shut it, and first one and then the other prevails.

The dancing of the valve in Walker's Air Compressor is reduced by causing a certain amount of friction to be set up between the spindle (*c*, Fig. 52) and one or more of its bearings. To accomplish this, where the spindle passes through the cross-bar (*p*, Fig. 52), the bearing is split longitudinally, so that the bore of the bush can be slightly contracted by means of a screwed spindle (*a*, Fig. 57), having a hand-wheel *b*, and lock-nut *c*, connected to the top half of the step. To provide a greater frictional surface, the spindle is made of larger diameter where it passes through the bearing, and is surrounded by a carbonite washer, which acts as a lubricant and prevents heating. Only a small amount of friction is applied, so as not to interfere with the free working of the valve to any appreciable extent. This device gets over the difficulty of "dancing" at ordinary speeds, but increases the power required to open the valve.

FIG. 57.



A very simple but effective device is in use at Lens Colliery (France). The inlet valves are of the ordinary poppet type, closing being effected by a spring, *a*, Fig. 58; when opened, however, the pull of this spring is taken off in the following manner: Each end of the cylinder is provided with two inlet valves, the spindles of which, *b*, pass outside the cylinder cover. Opposite these valves is fixed a small shaft *c*, which performs one revolution to each revolution of the engine, and on this shaft, opposite each valve, is keyed a cam *d*. At the commencement of the stroke, the face of each cam engages with the spindle of the inlet valve, pushes it wide open, and keeps it there. The small revolving shaft turns this cam, and its shape is so arranged that when the piston starts to make its return stroke, the cam is past the spindle, and the spring brings the valve back into its seat.

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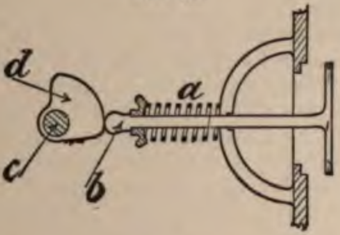
[*] *Compressed Air Production* (Wm. L. Saunders, New York, 1891), p. 20.

Conduits.—Air is conveyed from the producing machine to the motors through pipes, and a loss of work takes place from friction, governed by the following laws: (1) Resistance varies directly as the length of the pipe, (2) inversely as the diameter of the pipe, and (3) directly as the square of the velocity. The loss from the first law cannot be done away with, as it is impossible to alter the distance between the compressor and the motor. By using pipes of large diameters, the loss from the two latter laws can be kept within narrow limits, but the expense of doing so is considerable. The experiments at Paris* show that when the velocity in the pipes exceeds 50 feet a second, the loss in pressure becomes serious even in the distance of one mile. The loss, however, for two miles is not double that of one mile. The size of the mains can best be reduced by adopting high initial air pressures. Friction in mains may be reduced to a considerable extent by employing glass-lined pipes, an invention lately introduced.

FIG. 58.



Receivers.—From the compressors the air is discharged into a receiver, fitted with a safety-valve and pressure-gauge, placed near by, which not only serves the purpose of a reservoir, but corrects the irregular delivery from the compression cylinders. Receivers also rid the air of moisture, and should be so arranged that the air passes in and out on the same side. Drain-cocks are provided at the bottom, to get rid of the water. If the motors are any considerable distance away, small subsidiary receivers should be placed near to them in the workings.

Motors.—In these, the greatest loss takes place through leakage past the piston; with an ordinary engine the condensed moisture on the sides of the cylinders acts like packing, and helps to keep the piston tight; but compressed air is dry and hot, and leakage becomes serious. The most economical results are obtained by heating the air before it passes into the motor, which serves the double purpose of not only heating the air, but helps to pack the piston It, however, introduces this disadvantage, that the exhaust ports are likely to choke up with ice, through the moisture freezing; but this can be prevented, to a certain extent, by having large ports, and by allowing the exhaust to take place directly into the atmosphere, and not through pipes.

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* Inst. C.E. cv. 192.

ELECTRICITY.—It would be quite foreign, in such a work as this, to enter into an elaborate description of what electricity is, how it is produced, and the different systems and methods of using it; but as the mining engineer of the future will require to know a considerable amount about it, some brief description here will not be out of place. Every one is familiar with a magnet—its power of attracting bodies—and knows that each end is called a pole. This magnetic influence is exerted in certain lines, radiating from the poles, which were called "lines of force" by Faraday, who discovered that if a closed loop of wire were passed through them, a current of electricity was set up in the wire. This is the principle of the dynamo, which consists of a number of coils of wire revolving rapidly in a magnetic field. The electro-motive force depends on the rapidity of revolution, strength of magnet, and the angle at which the coils of wire pass through the magnetic field, which should be as near right angles as possible. The current, however, set up by such action does not flow in one direction, but consists of a series of reversals in opposite directions.

Alternating and Continuous Currents.—At this point is reached the division line separating the two systems of electricity. In one, the current is transmitted through conductors, and used as it is generated in the machine, that is to say, in a series of starts and stops or complete reversals, such being called the alternating current; in the other, by introducing into the dynamo a device called the commutator, the current produced in the armature is, so to say, straightened out, flows in one direction, and there is then obtained what is called the continuous current.

The latter is the system most generally applied, especially for the transmission of power, because up to the present, with probably one exception, an efficient alternating current motor has not been discovered. Once started, they work very well, but the great difficulty is to get them to move against a load. There is little doubt that this will be overcome, and then a very fine field will be open for such system, especially in mines, as an alternating motor is more compact than a direct-current one, possesses no commutator, or brushes, sparking only results by severing action, and the extreme simplicity of the winding and general construction makes it very unlikely to get out of repair.

The great advantage of the alternating system is the ease with which currents of high tension can be converted into currents of lower tension, but of a larger quantity. This is a point of considerable importance, because in mines it is often necessary, in order to obtain the fullest benefits from any system of transmitting power, that small machines can be worked at isolated points where required. Now, small motors developing a few horse-power are exceedingly difficult and costly to make to work with currents of high electro motive force. As pointed out further on, for any extended application of power, the cost of conductors can only be cut down by transmitting the current at high potential in the mains. To transform this into a lower pressure, is wasteful with the continuous current, and expensive machines have to be employed to do it. With the alternating system, however, the problem is a simple one. It is well known, that if two wires be placed side by side, not in mechanical contact, and a current passed through one wire, a current is developed in the second wire at the moment of starting or stopping the current in the primary wire. It therefore becomes necessary, if a permanent flow is to be produced in the second wire, that the current in the primary wire must consist of a series of starts and stops, which is actually what takes place in the alternating current system. If the two coils of wire are of the same length and diameter, the current in No. 2 will be the same as in No. 1, but if the relative length and diameter of the wires in the two coils are varied, and the secondary coil consists, comparatively speaking, of a few coils of a larger diameter wire, while the primary coil is a large number of coils of a smaller diameter wire, the current generated in the former will be feebler in its intensity, but larger in its quantity.

Terms Used.—The only difficulty in understanding the question of the electrical transmission of power consists in not knowing the meaning of the various terms used. The whole question of electrical distribution has been popularly illustrated by its analogy to hydraulics. Supposing a pump is circulating water through a circuit of pipes, every engineer understands the meaning of such terms as pressure, gallons per minute, friction, &c., when applied to such a current of water. If dynamo be substituted for pump, wire for pipes, and electricity for water, the conception of the elementary phenomena of electrical transmission by a continuous current becomes clear. In dealing with water, the pressure in lbs. per sq. in., the number of gallons to be delivered, and the friction of the pipes, has to be known; in electricity the pressure is spoken of as *Electro Motive Force* (usually written E.M.F.), and is measured by *volts*, the quantity is called *ampères*, and the friction is called resistance, and measured by *ohms*. To obtain the measure of electrical energy, the pressure (volts) is multiplied by the quantity (ampères), the product being volt-ampères, called *watts*. One watt = one volt × by one ampère, and 746 watts are equal to one horse-power.

As in hydraulics, the longer the pipes and the smaller their diameter, the greater will be the loss in transmission; so with electricity, the longer the wire, and the smaller its diameter, the greater will be the resistance and the loss. On the contrary, if the wire is short and its diameter large, no appreciable loss should (theoretically) result. The resistances of a long length of wire may be so great, that all the current may be wasted in overcoming them, and none reach the points where it is required to do work. In such a case, increase the size of the wire and lessen its resistance. Copper is the metal generally used for electrical conductors, and it is a costly one. The resistances in a long length of wire may be so great that, to overcome them, a wire of so large a diameter would have to be used, that its cost would be outside the bounds of possibility. One other alternative is open: increase the E.M.F. Electricians have from the first recognised the pressing necessity of a current whose voltage is as high as possible, since the cost of copper for line wire varies in the inverse ratio of the square of the voltage employed. Thus, supposing 2000 lbs. of copper are required to transmit a given quantity of power a certain distance under an E.M.F. of 50 volts, 125 lbs. only will be necessary if the E.M.F. is increased to 200 volts. For the voltage having been increased four times, the cost of line wire will be reduced sixteen times. Currents can be produced in practice, whose E.M.F. is 10,000 volts, and if a current of such high tension be used, the cost of conductors could be reduced to a minimum. This, however, is the point with which the mining engineer is directly concerned. Currents of high tension are dangerous; if the circuit became broken, the current would leap the break, and produce a spark which would ignite gas in a fiery mine; while if the current were by any accidental means passed through the human body, death would result. The colliery manager is, therefore, placed in a difficult position—he wishes to use high-tension currents for the sake of economy, and low-tension ones for safety. The general opinion seems to be, that 500 to 700 volts must be considered the maximum E.M.F. for use in mines.

Means to Prevent "Sparking."—The chief danger is feared from the production of sparks, either at the brushes, or by the severance of the cable. To remove the probability of gas being ignited by the former, Messrs. Atkinson * enclose the armature, brushes, and commutator in a casing, which bears on a turned ring fixed to the pole pieces, and also on a turned plate or ring which acts as a brush-holder, and which may be rocked like a brush-holder, so that the position may be altered to the point where sparking is *nil*. The safety arrived at by this method, depends on the principle of *excluding* gas.

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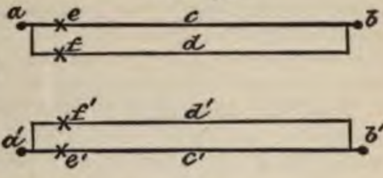
* Inst. C.E. civ. 93.

Messrs Davis and Stokes have recently patented an arrangement,[*] where the brushes are placed *inside* the commutator, and also enclosed in a casing; sparks take place inside the commutator, and cannot get through to explode the atmosphere outside.

To prevent the breaking of the cable by falls of roof or sides, and consequent sparking, the general method is to allow plenty of "slack" between the points of support, so that if a weight falls, the slack is drawn up, and the cable accommodates itself. To still further reduce the probability of severance, the cables at Plymouth Colliery[†] are protected by a double sheath of No. 8 steel wire on the outside of the insulation, the first stranding being of thirty-eight wires, and the second, thirty-six wires, laid in reverse directions. As a result, the cable is capable of resisting heavy falls, its tensile strength being about 30 tons.

FIG. 59.



Mr. L. B. Atkinson has recently introduced a safety cable,[‡] constructed on the following principles:—In Fig. 59, a, a' are the two poles of the dynamo, and b, b' those of the motor, or lamps. These are each connected by *two* wires, a main conductor, c, c', and a subsidiary conductor, d, d', which, as they are of the same length, carry current in proportion to their area. Cut-outs ($e\ e'$ and $f\ f'$), proportional to the carrying capacity, are arranged in each main, and in each subsidiary conductor. If the main conductor c gets broken, and the subsidiary conductor d does not, no spark is produced, as the circuit is still closed, but the whole current now passes through the secondary wire, and at once melts its cut-out. A weight suspended by the fuse then drops on to a switch, and the whole circuit is instantly disconnected. In its practical form, the cable consists of a close wound spiral of tinned copper wire, braided over, but not heavily insulated. Over this is laid a properly insulated stranded conductor of the required area. If the cable be torn down, or broken in any way by tension, this inner conductor extends to an indefinite extent, for as it gets drawn out, the diameter of the spiral decreases, and it becomes quite loose in its tube.

Efficiency.—The absolute efficiency of the ordinary means of producing the electric current by a steam-driven dynamo is small, as the electrical energy developed is only 6.4 % of the energy existing in the coal burnt under the boiler, and little advance is to be hoped for, so long as steam furnishes the motive power, as modern dynamos and motors have already high efficiencies in themselves. Looking at the ease with which electricity is converted into heat, it seems probable that the solution of the cheap generation of electricity will come about from the reverse operation. The direct conversion of heat into electricity has been possible since 1823, but the low efficiency of the process (only 0.35 % of the heat in the gas burnt) prevents its commercial application. Experiments are, however, being carried on, and the last results announce an efficiency of nearly 5 %, with hopes of a still greater increase. It is not too much to say that the discovery of a successful process with high efficiency, will revolutionise the generation and transmission of power.

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[*] Fed. Inst. ii. 161.

[†] Colliery Guardian, Sept. 4, 1891, p. 395.

[‡] *Ibid.*, Sept. 25, 1891, p. 525.

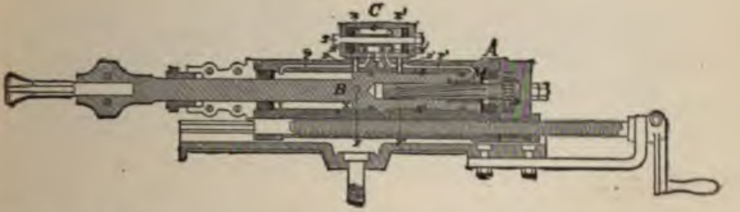
A new departure, giving great promise, was tried in 1891 at the Frankfort Exhibition. A dynamo 100 miles away produced three alternating currents of different phases at a tension of 50 volts, which were transformed into three currents of 17,000 volts, and conveyed along three wires $\frac{1}{6}$ in. diam. to Frankfort, where they were re-transformed into 60 volts, and used for the production of power and lighting in the Exhibition. The motors were of stronger construction than usual, thick bars and plates being used (suited to the work of a miner), instead of the fine wire and delicate insulation which so often gives trouble.

POWER MACHINE DRILLS.—These machines impart to the tool a reciprocating motion. They consist of a cylinder and piston, to the rod of which is attached a drill. The requirements of a good machine are, that it should be of simple and strong construction, occupy little space, be easily handled, and, above all, the wearing parts should not only be easy of access, but easily replaced when broken. As all the work of the drill is done during the forward stroke, while in the return only the weight of the tool and friction of the machine have to be overcome, the piston is reduced in area on one side. In order to bore a round hole, the tool is partly rotated after each stroke, and as the hole deepens, means are provided for moving the machine forward, so that each blow is delivered with full force. Numerous attempts have been made to perform the feed automatically, but although success has attended these efforts, the machines become much more complicated. With an automatic feed, the advance is regular, while often, owing to the varying nature of the ground, it is required to be anything but regular—sometimes faster, sometimes slower. Then, again, men have to be kept to look after drills while they are working, and may just as well employ themselves in feeding forward the tool to the best advantage, as to stand by and do nothing. In the old type of machine drills, the piston was made to admit and cut off the admission of air into the cylinder, by striking tappets attached to a valve, and although these parts were made as light as possible, yet for every stroke of the drill two blows were struck, with the result that the parts were rapidly worn away, numerous breakages occurred, and the expense of maintenance became very great. In modern power drills, the use of tappets has been abandoned, and what are known as steam (air) moved valves are adopted; their construction is therefore more simple, as the machine only consists of two moving parts. In some types, a further simplification has been carried out; by means of suitable ports and openings in the cylinder, the piston is made to admit and cut off steam by its own movement. They then consist of only one moving part, and that the piston itself.

It would be quite impossible to give a description here of even the majority of good machines that exist, so well known representatives of the two main types have been selected for illustrating the way in which they work.

The Ingersoll Rock-drill.—The cylinder A (Fig. 60) has admission ports, P, P′, and exhaust port E, and also two open passages, F, F′, connected direct with the exhaust port through the small passages, D, D′, so that if there were nothing in the cylinder to close D, D′, each end of the valve would be open to the exhaust. The piston B has, however, a movement from X to Y, and is provided with an annular space or chamber SS′, whose length is such that it can never be open to both the passages at D, D′ at the same time. The valve C is spool-shaped and travels on the guide-pin T. In the bottom of the steam chest are two passages *crossing* each other, which connect R with D′, and R′ with D. In the illustration the drill is ready to deliver a blow. Air is admitted at O, and fills the spaces N, N′ and R′. As R′ is connected with D, which is closed by the piston, no outlet is possible. R is connected to D′, and is open to the atmosphere through the annular space S and passage F′. No motion of the valve therefore takes place until the piston moves. Air passes from N through P′ to the back of the piston at M, and drives it forward; the exhaust passage SS′ approaches D, and when the distance DD′ is traversed, is open to it. At the same instant, D′ is shut off by the back end of the piston, D is suddenly opened to the atmosphere, and the chamber R′ being connected with it, is exhausted. The air around the valve rushes towards this opening, carrying the valve with it. Thus the valve is reversed, the machine exhausts, and the motion of the piston also reversed.

FIG. 60.



was 25%, while the hydraulic ones only had a duty of 8.5%. The speed of driving by hand was .0774 feet per man per shift; by compressed air drills, .423 feet per man per shift; while Brandt's drill advanced .472 feet per man per shift.

This machine can only be used in situations where water is easily got rid of. As a rule, mining engineers have quite enough difficulty in dealing with water already existing in mines without introducing any more.

Supports.—The supports upon which a drill was carried were originally either a rigid framework of clumsy construction, introduced with difficulty into narrow and uneven rock excavations, or a heavy carriage moving on rails, the latter, although carrying several machines, requiring that the road should be clear of débris before the drills could be set to work. The modern form consists of a vertical column (*a*, Fig. 62) resting on a base, in which lengthening screws are provided. By this means the necessary breadth of base is obtained to give stability to the column, and to permit the mounting on it of a swinging arm *b*, upon which the drill is attached. This arrangement allows the drill to be used upon all sides of the column, for drilling holes inclined in any direction. Bars are passed through the holes, *c*, *c*, in the top of the lengthening screws, and prevent them from becoming loosened by vibration. With a stretcher bar, drilling can be recommenced immediately after blasting, as the drill and column can be separately carried over the débris. With such a support, the machine is adjustable in all directions. It may be shifted sideways on the arm, raised and lowered on the column, and, by first

FIG. 62.

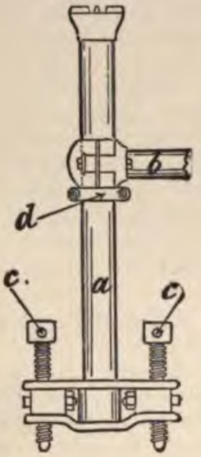
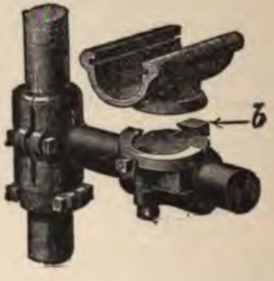


FIG. 63.



tightening the clamp *d*, the arm and machine may be bodily swung round the column.

Instead of attaching the drill to the clamp through a centre-bolt, the Rand Drill Co. have designed an arrangement (Fig. 63) in which the foot of the shell carrying the drill is made of a cone shape, and grasped by a hooked bolt *b*, which is distinct from the bolts binding the clamp to the arm. If a similar clamp is attached to a tripod, the drill can be changed from one support to the other with little labour, and without disconnecting the feed-screw and removing the machine from its guides, which has to be done with the old arrangement.

Where the length of the stretcher-bar exceeds 8 ft., an amount of objectionable vibration is set up, and, in high places, drills have to be mounted upon tripods. These consist of a light, strong frame, generally made of steel, consisting of three cylindrical telescopic legs, which can be lengthened or shortened to accommodate uneven ground. These legs are fastened into sockets in the top, and are kept in position by having weights hung upon them when the tripod is in place. The socket-joints are so designed, that the legs can be moved backwards or forwards, or one or more may be thrown up into the air out of the way, and indeed adjusted into any position whatever, so that the tripod may be adapted to the most uneven surface.

Electric Percussive Drills.—Numerous attempts have been made to construct a percussive electrical drill, but until recently with little success. The difficulty has been largely overcome by employing the principle of the solenoid. A solenoid consists of insulated copper wire coiled in the form of a spiral, but is only complete when a portion of the wire passes in the direction of the axis in the interior of the spiral. If a current be passed through a solenoid, it has the same power of attraction as a magnet.

In the Marvin drill,* two solenoids are placed against each other, end to end, and a plunger plays freely from the centre of these solenoids. The whole is placed in a boiler tube casing, having a spiral spring in the back part. The plunger is composed of a central portion made of wrought iron, and a forward and backward portion made of aluminium bronze, all rigidly connected together. The generator furnishing the current is of the simplest kind, so that the polarity of the wires is reversed at each half revolution of the armature, with the result, that through the action of this current on the solenoids, a reciprocating action of the plunger is obtained, as first one and then the other solenoid attracts it, and pulls it in opposite directions. About 600 blows per minute is found to be the best speed. The object of the spiral spring is to store up the energy of the back stroke, and return it in the forward stroke, helping the magnetic impulse, and greatly assisting the strength of the blow.

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* Eng. and Min. Jour., May 23, 1891, li. 600

In a trial made in the hard granite of Quincy Quarries,* a hole $1\frac{1}{2}$ in. diam. was drilled at an average rate of $2\frac{3}{4}$ in. per minute, with an expenditure of less than 4 H.P. delivered to the generator. The chief features, however, were the extreme ease with which the power could be transmitted from the generating station, and the great simplicity of the drill itself. For the purpose of exhibiting the ease with which the drill could be taken to pieces, and defective parts replaced by others, it was several times opened and entirely taken apart, the time required for this being less than three-quarters of an hour.

The Engineering and Mining Journal† states that the results obtained from the machines in practice are unsatisfactory, as not only are they of faulty construction, a defect probably easily corrected, but they present a more serious trouble—viz., the heating of the solenoids and piston. The heating of the solenoids seems to be due to the rapid reversing of the electric current through their coils. This not only means loss of efficiency, but the heating is often so intense as to make the drill objectionable in a small heading. An important installation of these machines was made at Lake City, Colorado, in 1891, but after experiments through September and October they were withdrawn owing to the objectionable heating. The inventors are now endeavouring to overcome the defects thus shown, with every probability of ultimate success.

Forms of Bit.—Like ordinary hand tools, the first form of bit for machine drills was that of a chisel. In order, however, to obtain more striking surface, two chisel edges crossing each other at right angles were tried. This did the work better, but as the hole got deep, ready escape of the débris was prevented, as the tool nearly filled the hole. To remove this difficulty, the two chisels were made to cross each other on a slope, forming a tool like the letter **X**, which is the shape now generally adopted. Bits like the letter **Z** have been tried with most satisfactory results, so far as the efficiency of the boring is concerned, but the difficulty of sharpening them prevents their general application. For making and dressing the drill bits, a set of tools called "swages" are employed. These are like moulds, shaped to the form of the bits required.

Use of Water in Boring Holes.—Experience has proved that by using water in the holes the speed of drilling is considerably increased, and such is always done in drilling down-hill holes. With up-hill holes, water cannot be employed with ordinary means. Messrs. Dubois and François exhibited at the Paris Exhibition a device which has overcome the difficulty. Water is injected right on to the cutting edge of the drill, instead of simply into the mouth of the hole. A small copper pipe is fixed in a groove extending throughout the length of the drilling bit, and is connected by a small flexible tube to a tank fitted to the back of the piston-rod, but prevented by suitable means from rotating with it. With each stroke of the piston, water is thrown right on to the place where the cutting edge strikes, the bottom of the hole is always kept clear, and the full effect of the blow from the drill is obtained; the deeper the hole, the greater the effect.

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* Eng. and Min. Jour., April 4, 1891, li. 400.

† Vol. lii. 720, Dec. 26, 1891.

Cost of Machine and Hand Drilling.—For two years at Ramsbeck lead mines,* careful comparisons have been made between the cost of driving levels by hand and by machines. The strata consist of hard schists and greywacke. With hand boring, the average speed of driving double tramway roads was found to be 9 ft. 10 in. per month, while with machines it was 35 ft. The saving, taking economy and *speed* into account, was 304 per cent.

Saving in money by using machine drills . .	£116	14	5
„ „ per yard driven . . .	1	11	3
„ „ per cent.		20.6	

Interest on capital and amortizement was taken at 13 per cent. Repairs to drills amounted to 10.49 per cent. of the total working cost.

Experiments have been conducted at the Rammelsberg Mine in the Hartz,† where six types of machine drills have been tried for several years. It appears there was a saving equal to 2*s*. 3.89*d*. per ton of ore won in favour of machine as compared with hand drilling, including all costs, during the year 1880-81. The saving in favour of machine drilling for the years 1877, '78 and '79, was 10.39*d*., 1*s*. .07*d*, and 1*s*. 5.2*d*. per ton respectively, which shows a progressive increase, probably due to improvements in the machines and training of the men.

The following figures relating to the Vosberg Tunnel, U.S.A.,‡ show the difference in the speed of machine drilling compared with hand:

	East End.		West End.	
	Length. (ft.)	Excavation. (cub. yds.)	Length. (ft.)	Excavation. (cub. yds.)
Hand drilling . .	60.81	537.50	65.73	419.62
Machine drilling . .	181.11	1069.27	138.63	1095.77

Average for hand drilling, both ends, 63.27 feet, for machine drilling, 159.87 feet; a gain in speed equal to 252.7 per cent.

COAL CUTTING BY MACHINERY—Under suitable conditions, coal can be holed much cheaper by machinery than by hand, except, probably, when wages are low. The great advantage, however, is that less small coal is produced, as with the pick a man, to under-cut a certain distance, has to remove enough height at the face to get his arms in. To a certain extent, machines cannot well be used in old mines, the work requiring to be specially laid out for them. With a good roof requiring little timber, they are used with a considerable amount of success, but in a tender coal, the roof is crushed down upon them, or supports have to be set near the face. These get in the way of a machine, which cannot move round them like a collier. The different types employed may be divided into (*a*) the circular-saw class, (*b*) the band-saw class, (*c*) the percussive, and (*d*) the bar type.

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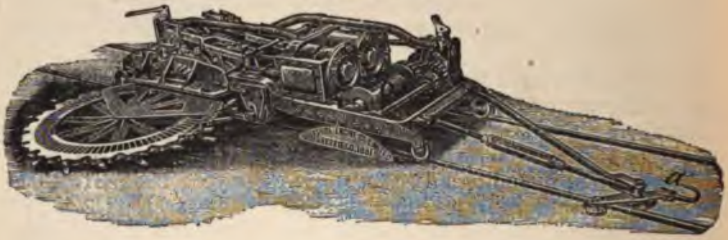
* For. Abs. N.E.I. xxxi. 24. † *Ibid.* xxxii. 43.

‡ *The Vosberg Tunnel* Leo. von Rosenberg (New York, 1887), p. 26.

Machines worked by Compressed Air.—*Gillott and Copley's* is a representative of the circular-saw type. The cutter wheel is a malleable-iron disc, 4 ft. diam., furnished on its outer periphery with a series of chisels, these being of two kinds, single and double, placed alternately. Power is supplied by an engine having cylinders 9 in. diam. by 10 in. stroke, geared down about 5 to 1. The machine is drawn forward by a wire rope, which is attached to the hook (*a*, Fig. 64), then passed round a pulley at the end of the face, and finally brought to, and coiled on, the drum *b*, by the action of a ratchet-wheel and pawl, which can be so regulated that either one or more teeth are taken at a time, thereby allowing the machine to be fed slower, if the under-cutting is hard. This machine cuts from back to front, and brings its débris out, if the cut is above the floor.

FIG. 64.

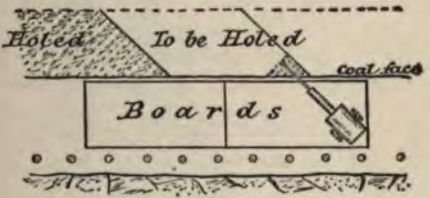


Rigg and Meiklejohn's machine also cuts like a circular saw, but with this advantage: it holes into the face on the underside of the sleepers; or, in other words, flush with the bottom of the coal. It can be employed in the thinnest seams, as its height is only 16 in. It is provided with four adjustable screws, one on each corner, by means of which the cutters can be made to work at any angle, and the axle-boxes are also adjustable to allow the machine to progress at any angle, irrespective of the level of the rails. It revolves, however, from front to back, and carries the débris into the cut, requiring the services of an assistant to clean it out. The cut can be made alternately in opposite directions.

Baird's machine represents the band-saw-type. The cutters are of various shapes, and are mounted on an endless chain, carried by a jib which projects beneath the coal, from 3 ft. up to 5 ft. as required. Motion is given by an 8 in. cylinder by 12 in. stroke engine, through gearing, to a cylindrical shaft in the centre of the machine. On the bottom of this shaft is a cam, or sprocket wheel, which drives the chain carrying the cutter teeth. As this chain has to be carried over the top of the rails, the machine cannot undercut in the bottom of the seam unless the floor is taken up. The difficulty is got over to a certain extent by canting the machine when at work.

Harrison's machine, which is largely employed in the United States, consists of a percussion drill which chips away the coal. A broad pick bit is secured to the end of the piston-rod of a small cylinder mounted on wheels. The cutting tool is chisel-shaped, with a triangular slit in its face. To perform the undercut, two boards, 6 ft. by 3 ft., are laid on the floor close to the face and slightly inclined towards it. The machine, mounted on 14 inch wheels, is run on these boards, air turned on, and the face attacked at the angle shown in Fig. 65. The machine is balanced on the wheels, and the operator, lying behind it, sprags the wheels with his feet, keeps the machine up to its work, and by means of the handles swings it about and regulates the direction of the blow.

FIG. 65.



Machines of a similar type have often been designed, but the violent shock against the rear head of the cylinder, when the piston made its backward movement, not only made it impossible to keep them to their work, but broke them to pieces. India-rubber cushions are not sufficient remedy for this evil. Here the difficulty is surmounted by interposing between the piston and cylinder head, an air-cushion of adjustable pressure, and in addition the valves are so arranged that the rebound of the pick actually aids in moving them. Prof. Wheeler * states that it takes about 6 minutes to shift the boards, 1½ min. to change the bit, and 16 min. to cut 4 ft. wide by 4 ft. deep. To disconnect, load up the outfit on a truck and remove to the next place, unload and start to work again, takes about 20 min. The cutting capacity is found to be between 60 and 70 lineal ft. per 10-hours shift, with an air pressure of 80 lbs., the average for six machines for a month being 63.8 ft. A Harrison machine weighs only 700 lbs. and costs about £120. The cost per day for power, repairs, interest, and depreciation, is put at 3*d*. per ton.

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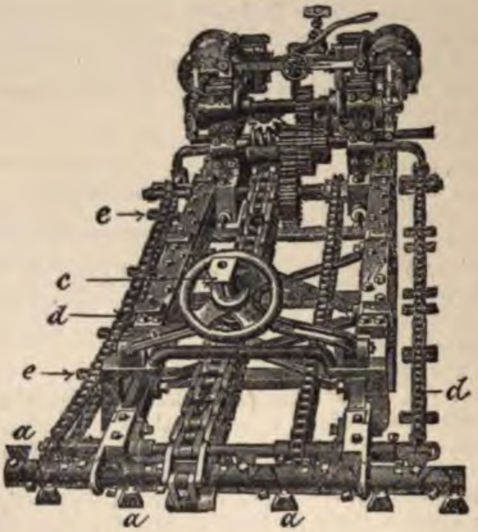
* School of Mines Quarterly, New York, ix. 308.

The *Ingersoll-Sergeant* machine is similar in general appearance to the Harrison, but is furnished with an air-moved valve like their drills. It is claimed to be simpler in construction, to be more under control, to deliver a harder blow, and to be more economical in air than the Harrison.

The *Legg* coal-cutter is a representative of the bar type, and differs from all others not only in the way power is transmitted to the cutter bar, but in the direction in which the cut is made. The machine consists of a bed frame, occupying a space about 2 feet wide by 7 ft. 6 in. long, composed of two steel channel bars, the top plates on each forming racks, with the teeth downwards, into which the feed wheels of the sliding frame engage. On the rear end of the latter is mounted a pair of 5 in. by 5½ in. engines, from which power is transmitted through straight gear and worm wheels to the rack, which feeds the sliding frame forward. The cutter-bar is mounted on the front end of this sliding frame, and contains the bits, *a*, *a* (Fig. 66), made of tool steel, held in place by set screws, and so set in a spiral along the horizontal bar as to make a continuous semi-cylindrical cut in one revolution. The cutter-bar is revolved by an endless curved link steel chain *b*, and as it is

FIG. 66.



revolved, is advanced into the coal, the bed plate being clamped firmly by two braces fitted with lengthening screws, one of which is shown at *c*. Small link belts, *d*, behind the cutter-bar, push back the chippings produced during holing, by the aid of the short projections, *e*, *e*, and keep the under-cut free.

The essential difference between this and other machines, is the direction in which the cut is made. Here it is parallel to the face, while in all others it is at right angles. This machine really does its work in the same direction as a miner. When the cut has reached the required depth, usually about 5 ft., the bar is thrown out of gear and withdrawn, the machine moved sideways along the face over the length of the cutter-bar, and another cut made. This gets over two disadvantages: (*a*) the inability of most coal-cutters to work in stalls which are set with timber at short intervals, since so long as the props are wide enough for this machine to be got between (about 3 ft. 6 in.), it can easily be placed in position, even if they are close to the face; (*b*) the irregular holing generally produced when the floor of the seam is undulating. Rotary wheel machines must cut a straight groove; this machine can follow any variation in the floor which takes place within the length of the cutter-bar.

The rapidity of the cutting is claimed as a further advantage of the machine. It is, however, expensive in first cost, and in repairs. The present cutter-bar is, however, an improvement on those formerly used. Instead of being weakened at the sprocket by being squared to admit the straight link driving chain formerly used, it is now increased in diameter at this point, made round, and a curved link-chain used, thus not only strengthening the bar, but greatly increasing the leverage of the chain, which lessens the power required, and reduces the friction and wear on the chain. The feed can readily be thrown off and on by means of a lever.

Machines Driven by Electricity.—Although machines under-cut coal cheaper than manual labour, under suitable conditions, the difficulty of driving them by compressed air or wire ropes, nullifies the advantages to a certain extent, even where favourable conditions exist. The cost of installing compressed air is not only considerable, but its transmission to the face presents serious difficulties in coal mines; not only are the pipes expensive, but the cost of labour in laying them is large. If the pipes are carried along the side of the road on supports, any fall of roof or sides will break them; while if they are buried beneath the floor, leaks cannot be detected. These latter considerations are not so important in the main roads as they are in those approaching the face which are constantly being altered in dimension, and in which repairs are frequent.

Electricity appears to be particularly applicable to the operation of coal-cutting. In the facility with which power can be carried about, this medium stands unrivalled, and the cost of up-keep is less than with other systems. The only objection seems to be the danger that may result from sparking at the motors in situations where explosive atmospheres exist. In the author's opinion this danger appears to have been exaggerated. In the first place, the great majority of mines do not contain explosive atmospheres, and in the event of a sudden outburst of gas, the motor might be immediately stopped. Sparking at known points, or by short circuiting, appears to be preventible, as it depends on the design of the machine, on the intelligence of the workmen operating it, and last, but not least, on the common-sense of the purchaser. In the desire to secure economy in outlay, less money is often spent on safeguards than should be the case.

The *Goolden*[*] cutter consists of a long bar, taper or parallel, having a series of steel tools arranged on it. This bar is rotated at the rate of about 500 revolutions per minute, the electric motor running at about 700 revolutions. The cutter-bar is drilled with a series of holes, each of which is placed in a direction nearly, but not quite, at 90° to the next adjacent one, with the result that the cutters form a left-handed spiral, which serves to equalise the cutting action, and also a right-handed spiral, which acts as a sort of corkscrew, and draws the débris out of the cut. After trying various forms for the cutters, a **V**-shape has been adopted, with the edge nearest the machine sloping across the cut; so that when the tool has entered about $\frac{1}{8}$ or $\frac{1}{4}$ in. a wedging action commences, and the ridge of coal left between succeeding cutters is split off.

This machine is practically the only one which has been at work in England. Messrs. Atkinson state that on an average 20 to 30 sq. yds. per hour may be cut in fairly hard coal, all stoppages being included, while as a maximum performance, 55 yds. were holed an average depth of 3 ft. 8 in. in 75 minutes at Nostell Colliery.

The *Jeffrey* machine, which is most in favour in America, consists practically of the Legg machine, already described, with the ordinary engines replaced by an electric motor. The current required is from 30 to 50 ampères at a pressure of 220 volts; the armature is calculated to run at 1000 rev. per min., while the cutter-bar makes 200 revolutions. The momentum of the armature is such, that obstructions met with by the cutter-bar are not perceptible, so that the machine is caused to run steadily. Mr. H. C. Spaulding[†] states that 23 of these machines have been applied, and that the amount of work done by each averaged from 600 to 900 sq. ft. of under-cut in 10 hours.

Van-Depoele.[‡]—A machine of the percussive type has recently been placed on the market in America. With a stroke of from

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[*] Inst. C.E. civ. 104.

[†] Amer. Inst. M.E. xix. 276.

[‡] Eng. and Min. Jour., Aug. 29, 1891, p. 245.

	In a Seam 3 feet thick.			In a Seam 1 foot 6 in. thick.		
	Nature of Holing.			Nature of Holing.		
	Favourable.	Hard.	Very Hard.	Favourable.	Hard.	Very Hard.
Price for getting coal by hand per ton	1/6	1/8	1/10	3/2	3/6	3/10
Percentage of slack by hand	35	40	45	45	50	55
Do. by machine	20	20	20	30	30	30
Average selling price per ton, round (including nuts), @ 6/- per ton, hand	4/9.3	4/7.2	4/5	4/5	4/3	4/1
Do. slack, @ 2/6 per ton, machine	5/4	5/4	5/4	4/11.5	4/11.5	4/11.5
Price for filling out coal with machine holing, including getting bottom up	1/-	1/1	1/2	2/-	2/1	2/2
Yards holed by each machine per day of 16 hours	200	160	120	200	160	120
Holed by 8 machines, per week . . . tons	8,000	6,500	4,900	4,000	3,250	2,450
Do. in 48 weeks, say . . . tons	384,000	312,000	235,200	192,000	156,000	117,600
Cost per ton for holing by machine: Labour (1 man @ 6/- per day, 1 @ 5/- per day)	1.6	1.9	2.6	3.1	3.9	5.1
Allowance for first cost of plant (£900 per annum)	.6	.7	.9	1.2	1.5	1.9
Do. power (£1210 per annum)	.8	.9	1.2	1.5	1.8	2.5
Total cost of coal-getting by machine	1/3.0	1/4.5	1/6.7	2/5.8	2/8.2	2/11.5
Saving as compared with hand labour	3.0	3.5	3.3	8.2	9.8	10.5
Saving in yield of coal	6.7	8.8	11.0	6.5	8.5	10.5
Total saving	9.7	1/0.3	1/2.3	1/2.7	1/6.3	1/9.0

in Germany by the use of rye straw for charcoal, carbonised to brownness, with sulphur reduced from 10 per cent. to 3 per cent. The problem is to get rid of the sulphur altogether.

The so-called smokeless powders may be defined as chemical compounds, and generally consist of gun-cotton and picric acid, sometimes alone, sometimes in combination, mixed with retarding agents to prevent detonation. The absence of smoke is a great advantage, but safety in storing and reliability in keeping quality is greater. The slow-burning character of gunpowder makes it an admirable rending compound. It gives out its energy in a constant heaving force, and brings down coal in large lumps. No other explosives do so; their energy is locally developed, smashing up such a soft substance as coal, and entailing a loss to colliers and colliery owners. So far as cost is concerned, gunpowder compares favourably, in all ordinary operations, with any other explosive. So long as powder will blow the bottom of the holes out, nothing is gained by using more powerful explosives; but in strong rocks, the employment of powder means shallow holes and slow progress. Where everything is sacrificed to speed, the holes are bored deep. and sufficient explosive used to break up the rock into small fragments, and so hasten its subsequent removal. Gunpowder possesses an advantage which is not shared by any other explosive: it can be used either with or without detonators, and be made to do more work at will.

Nitro-Glycerine.—This substance is formed by the action of a mixture of nitric and sulphuric acids on glycerine. It is a bright, oily, colourless and odourless fluid, has a faint sweet taste, and is poisonous, causing headache and colic. It is such an unstable compound, that its use has been forbidden by law in this country and in several continental ones; but, mixed with other substances, it forms the base of the majority of modern high explosives.

Dynamite is a plastic substance of reddish-brown colour, consisting of nitro-glycerine absorbed in porous kieselguhr, which is earth consisting of the shells of diatoms (nearly pure silica), found in Hanover and other localities. Many other absorbent materials have been tried, but kieselguhr has given the best results. This choice has been further justified by the absence, after explosion, of the noxious fumes of carbonic oxide, which render charcoal, although equally absorbent, so hurtful to the health of the miner. Ordinary dynamite contains 75 parts of nitro-glycerine and 25 parts of kieselguhr. In the open air, *in small quantities*, it burns freely, quietly, and without explosion. One advantage of the dynamite class of explosives is that they are plastic, and therefore, when tamped, fit accurately into the hole. Metal rods, or rammers, should never be employed to tamp the charge. A wooden rod should be used, and the cartridges gently, though firmly, squeezed into place.

Blasting Gelatine is said to be the most powerful of known explosives, and is a tough, slightly elastic, semi-transparent substance, resembling ordinary gelatine. It contains 93 per cent. of nitro-glycerine, together with 7 per cent. of nitro-cotton, and on explosion resolves itself into carbonic acid, water, and nitrogen, there being just enough oxygen to combine with the carbon and hydrogen. It is stated to be 50 per cent. stronger than dynamite, and more insensible to shocks than that substance.

Gelatine-Dynamite.—This is a compound better known to miners and contractors, being more used for blasting in rock which is required to be removed in as large pieces as possible, as its action is a heaving and rending, rather than a disruptive one. In appearance it is more opaque than blasting gelatine, and consists of 80 per cent. of that explosive, with nitrate of potash and wood-pulp added in proportion.

Gelignite is similar in composition. It consists of 65 per cent. of blasting gelatine and 35 per cent. of the absorbing powder.

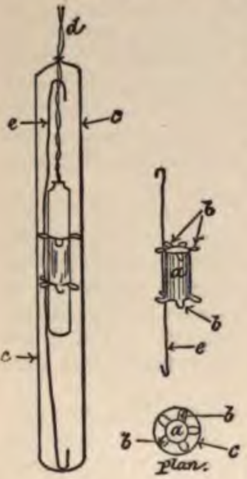
In cold weather, all nitro-glycerine compounds freeze, even at a temperature of 46° F., and are very dangerous to use when in such a state. The cartridges may, however, be softened, without danger, in warm-water warming-pans. They must not be put in the warm water to do so, but first in a water-tight vessel, and then that vessel placed in warm water.

Rackarock.—This explosive is largely employed in America. It is composed of 80 per cent. of potassium chlorate and 20 per cent. of nitro-benzol. The former of these ingredients is solid, and the latter liquid, and both are non-explosive during their manufacture, storage, and transport. Little danger attends the use of this explosive as explosion can only take place after mixture, this being generally done immediately before charging.

BLASTING IN DRY AND DUSTY MINES.—The passing of the Mines Regulation Act, 1887, materially modified the use of explosives underground, as General Rule 12 states that "in places likely to contain either accumulations of gas or coal-dust, a shot shall not be fired unless the explosive is so used with water or other contrivance as to prevent it inflaming gas, or is of such a nature that it cannot inflame gas." The one fault of gunpowder is that it gives off a certain amount of flame on explosion, and its use is, therefore, not allowable under the circumstances just stated. To meet the altered conditions, and yet to continue the use of explosives, numerous methods have been proposed.

Water Cartridge.—A cartridge of gelignite (usually of such a size that only one is necessary) is held in a skeleton case (*a*, Figs. 68–70) having a number of thin metal diaphragms *b*, which keep the cartridge in the centre of the case (*c*, Figs. 68 and 70) containing the water. A detonator is inserted into the last cartridge, and a fuse, or electric wires, passed from it to the outside of the bore-hole. The space between the charge and the case is filled with water, and the outer end firmly tied round the projecting fuse or wires *d*. A guide wire *e*, is also placed in the bag to keep the charge in the centre long ways. The objections to this apparatus are (1) the large number of parts and delicate handling they require; (2) the water acts as a sort of cushion between the explosive and the sides of the hole and so lessens the effect; (3) the large-sized hole which has to be bored; (4) and a liability of rupturing the case and letting out the water.

FIGS. 68, 69, AND 70.



To overcome these disadvantages, which reduce efficiency and convenience, several new explosives have been developed.

Roburite.—This belongs to the hydrocarbon class of explosives, and consists of two compounds (which are harmless and inert separately) mixed and ground up together in a mill, the resulting product having a sandy granular appearance, resembling common yellow sugar. The two substances are nitro-benzol and ammonium-nitrate, the latter being the oxygen-yielding body. During the process of mixture these two substances are subjected to a process of chlorinisation, with the result that the compound produced, upon being detonated in the usual manner, evolves gases which quench any flame produced by the explosion. The practical effect is somewhat similar to that produced by the water cartridge, with the distinction, that the quenching element being chemically combined with the explosive, there is a smaller risk of failure. Roburite cannot be exploded by blows of a hammer, as it requires a very powerful detonator, and when ignited burns slowly. It is very safe, as far as regards storing, and has more of a heaving action than the nitro-glycerine class. It does not freeze when exposed to cold, but is affected by damp and loses power, although its strength can be restored by drying; the cartridges are, however, placed in a special waterproof covering, which, to a certain extent, removes this disadvantage. Statements have been made from time to time that the fumes produced on explosion have an injurious effect on the health of the workmen, but in every instance where these have been investigated (in Lancashire and the North of England) no ground has been found for such complaints.* Some cases of illness have been traced to its use, but these have generally been found to be due to the neglect of the proper precautions in its use which are published by the manufacturers. Workmen having cuts, or skin knocked off their hands, should be careful when handling the cartridges, and should wash their hands before eating food, or there is a danger of some of the substance getting into their mouths.

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* Fed. Inst. ii. 368.

Ardeer Powder.—Under this title Messrs. Nobel have recently introduced an explosive practically identical in composition with "Grisoutite," which has given such good results, and has met with much favour on the Continent.[*] The base of the compound is dynamite mixed with 45 per cent. of Epsom Salt. This substance contains 51 per cent. of water, and is introduced for the object of reducing the temperature of the products of explosion.

Carbonite is another explosive of late introduction. It is said to be composed of nitro-glycerine, sulphur, and nitro-benzol.

Tonite.—Tonite, which consists of 52.5 per cent. of gun-cotton and 47.5 per cent. of barium nitrate, by itself fires gas in the same manner as ordinary gunpowder, but, if tamped with Trench's Compound, flame produced by the explosion is quenched.

Ammonite.—An explosive of recent introduction is that known as Ammonite or Favier's explosive, which belongs to the hydrocarbon class, being composed of ammonium nitrate and nitronaphthalene. It can only be exploded by a very strong detonator, is not affected by heat or cold, but readily by moisture; for this reason each cartridge is enclosed in a tinfoil case hermetically sealed, which has to be cut into just before use to insert the detonator.

There are numerous other new explosives each claimed by the makers to possess advantages over the others. All are stated to be flameless, but none are absolutely so. Everything seems to depend on the tamping. Mr. Walton Brown [†] states that the experiments of the French Commission showed that the retardation of ignition characteristic of fire-damp mixtures, the almost instantaneous mixture of the gases resulting from the explosive with the surrounding atmosphere, and the quick cooling consequent thereon, combine to make explosives, whose temperature of detonation is less than 4000° F., incapable of igniting explosive fire-damp mixtures under normal conditions of use; that is to say, if properly stemmed. The degree of safety becomes greater as the temperature of detonation falls below the above value. With any of the dual mixture explosives, the greatest care in manufacture is necessary, as it is essential that perfection be ensured in the mixture. The safety of ignition in explosive atmospheres also depends upon the almost instantaneous mixture of the gases resulting from detonation with a sufficient volume of surrounding air, it being highly probable that it may be dangerous to fire a shot in a too limited space, and with a weight of explosive too great for the volume of the surrounding air, as compared with the volume of the gases produced by the detonation.

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[*] *La sécurite de minage à la grisoutite dans les milieux grisouteux et poussiéreux.* A. Macquet. Mons. 1889.

[†] Fed. Inst. ii. 488.

Firing the Charge.—Explosions may be divided into two classes—(*a*) where combustion proceeds slowly through the mass of the compound, and (*b*) where instant ignition takes place, called detonation. The power in (*a*) is applied slowly, with rending effect; while in (*b*) the gases are instantly generated, their force is localised, and a shattering effect results. To produce the latter action detonators have to be used, these consisting of a small quantity of a powerful explosive, fulminate of mercury, enclosed in a copper capsule.

Three modes of firing charges are in use—(1) squibs or Germans, (2) fuses, (3) electricity. The first can only be employed with gunpowder, but the second and third with any explosive.

(1) **Squibs, or Germans.**—These consist either of a straw or paper spill filled with fine powder. When "Germans" are employed, a copper rod, about $\frac{5}{16}$ in. diameter, called a "needle," has to be inserted in the hole during tamping. This needle reaches from the outside to the cartridges, and is turned from time to time to prevent it getting jammed, and finally withdrawn, leaving an open passage through the tamping to the powder. The squib is then inserted in this hole, and a slow match applied to the outside end.

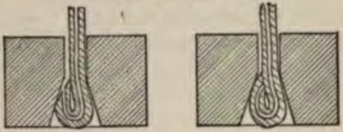
(2) **Fuses.**—Frequent misfires with straw squibs, and premature explosions, together with the production of a shower of sparks, led to the introduction by Bickford, in 1831, of safety fuses, the principle of which is to enclose a thin string of gunpowder in a sheath of some material or combination of materials, with a view of protecting the core from rough usage and moisture. Many different qualities are made to meet the varying conditions of employment—viz., the time stored before use, influence of climate, temperature of mine, and presence or absence of moisture.

For ordinary work the thread of powder is protected with rope yarn, coated with different varnishes, or, if moisture is present, a further lining of tape and varnish is given. For blasting under water, gutta-percha coverings are employed, but such fuses cannot be stored long, owing to the rapid oxidation of the gutta-percha. To prevent this, an exterior coating of tape and composition varnish is applied, which not only delays oxidation, but retains the efficiency for a long time. Metallic fuses, in which the core is covered with lead pipe, have been introduced, but are not much employed, owing to their weight, brittleness, and liability to damage by torsion.

Ordinary fuses are sold in coils 24 ft. long, and burn at the rate of 2 ft. per minute. Misfires occur, generally through deterioration and the use of inferior qualities. The store-room should be dry, or the powder will be affected, and the fuse should not be in contact with any oily or greasy article. All gritty and sharp substances should be avoided in ramming, as the fuse is often cut through, and a misfire follows.

Under the Mines Regulation Act, powder can only be taken into a mine in cartridges. These generally consist of a reel, or bobbin, of compressed powder, having a hole, conical at one end, passing through the centre. In firing with a fuse, it is first cut to obtain a fresh surface, and threaded through the bobbin. One end of the fuse is doubled back into the conical hole at the bottom of the cartridge, and pulled tight, the subsequent bobbins being threaded over the front. In doubling the fuse back to bind it in the cartridge, care should be taken that the string of powder rests directly against the cartridge (Fig. 71), and not against the return portion of the fuse (Fig. 72). Numerous misfires may be traced to the neglect of this simple precaution.

FIGS. 71 AND 72.

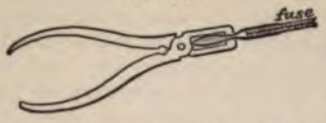


With detonating explosives, a piece of safety fuse is cut clean, and inserted into a detonator until it reaches the fulminate. The upper part of the cap is then squeezed with a pair of nippers, with a view not only of securing the fuse in position, but also of developing the power of the fulminate.

For use under water, care should be taken to make the upper end of the detonator water-tight, where it joins the fuse. With nitro-glycerine explosives, a cartridge is opened at one end, the detonator pushed in (leaving about one-third of the copper tube outside the cartridge) and securely tied in position. The detonator should not be pushed too far into the cartridge, or the fuse may set fire to it before the spark can explode the detonator. Holes are charged by putting in one or more cartridges, and squeezing each with a wooden rammer, a cartridge with detonator and fuse is then inserted, *but must not be squeezed.* Loose sand, or water, is all that is required for tamping, but the power of the explosive is increased by tamping. A good plan is to insert on the top of the priming cartridge and detonator a ball of soft clay and press it home, then put further tamping on this.

In firing shots in mines, where naked lights are not allowed, a small copper wire is commonly employed, one end of which is made red-hot by putting it into the flame of a safety lamp, while the other is inserted into the fuse. The wire is generally passed through a small hole in the glass of the lamp. To get rid of the difficulty of passing wires into lamps, and prevent the emission of sparks when the fuse is fired, Messrs. Bickford have designed an ignitor, which consists of a small tin tube, containing a small glass phial, holding sulphuric acid, resting against a small quantity of chlorate of potash and sugar; one end of the fuse is inserted into the open end of the tube, and the glass phial broken by gripping the tube with a pair of pincers (Fig. 73). The sulphuric acid acts on the mixture, lights the end of the fuse, and all sparks produced are kept within the tube.

FIG. 73.



At the Aubin Colliery in the department of Aveyron, France, a modification of the device for lighting pipes, cigarettes, &c., by the heat generated by the compression of air, has been in use for some time. It consists of a metal cylinder, in which a well-fitting piston moves, the rod of this carrying a cross-piece so that a firm hold is given for the hand. One end of the fuse is passed through a small hole in an india-rubber ring into the cylinder. A quick and strong thrust is given to the piston, the air in the cylinder is compressed and heated, and the core of the fuse ignited. It is said that, with a little practice, ignition always takes place at the first thrust, and as the sparks from the burning of the first inch of fuse are thrown out inside the cylinder, they are thereby cut off from the surrounding atmosphere.

Blasting by Electricity.—The practice of igniting shots by the aid of the electric current has been gaining ground for a considerable number of years; with it, no question can arise as to whether shots have missed fire or not. Ignition with ordinary fuse sometimes hangs for a considerable time, even up to twenty-four hours; sparks from the fuse are got rid of by numerous devices, but as no sparks are produced by electricity, it must be better. Then again, there is no chance of premature explosion. Every one can be in a place of safety before the shots are fired; indeed, in some collieries where blasting might produce an explosion, all the shots are fired from the surface when the pit is free from men.

Two systems are in use; in one, electricity of high tension and small quantity is employed, while in the other, the electricity is of low tension and of large quantity. The former are called "tension," or "machine," fuses, and the latter, "quantity," or "battery," fuses.

Tension Fuses.—These consist of two copper wires, with the ends separated from each other by a small interval, in which is placed a priming composition, and the whole inserted into a detonator. The current, in leaping across the interruption, meets with great resistance from the low conductivity of the material passed through, heat is generated, and the priming and detonator fired. The priming composition generally employed is known as "Abel's," and consists of a mixture of 10 parts of sub-phosphide of copper, 45 parts of sub-sulphide of copper, and 15 parts of chlorate of potash, well rubbed together in a mortar, with sufficient alcohol to moisten the mass, and afterwards carefully dried.

Quantity Fuses.—Here the two copper wires are joined together by a very thin, short length of platinum wire, and surrounded by a substance inflammable at a low temperature. The current passing down the copper wires meets with great resistance in passing across the small section platinum wire, and generates sufficient heat to fire the priming. As the circuit is uninterrupted, *quantity* only is required to heat the wire to redness, and therefore an ordinary battery may be used.

Comparison.—The advantages of high tension lie chiefly in the convenient form and ready action of the machines employed to excite electricity. These are of small dimensions, light weight, simple in construction, and do not readily get out of order. In addition the means of discharging the machine may be removed until the required moment. For this reason, such system is useful in mines where the operations are carried out by men of no scientific knowledge. A great advantage, however, is the fact that a large number of shots can be fired simultaneously with more certainty than with a battery, and that line resistance has a small effect on the current, so that cables of small diameter can be used.

The disadvantages are, that the fuses are more or less affected by moisture and heat, and that the wires carrying the current have to be well insulated. Low tension fuses are more trustworthy than high. Certainty of action is always possible, as each fuse can be tested before use by passing a weak current through it, and the insulation of the line wires need not be very perfect. For ordinary mining work, low tension is not so convenient as high tension. In the first place, only a limited number of shots can be fired simultaneously, unless a large battery power is available. Batteries soon get very cumbersome, and, furthermore, always require a considerable amount of attention. Low tension fuses can, however, be fired from an electric light or power circuit while high tension ones cannot, and as dynamos are becoming common at collieries the natural result is that low tension fuses are more and more applied.

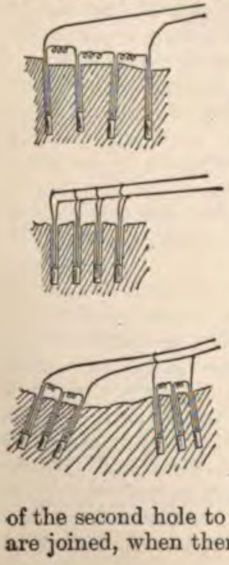
For firing tension fuses, two types of machines are employed—(*a*) those in which the current is generated by friction, (*b*) the magneto type.

Frictional Machines.—The machine most in favour is that of Bornhardt, which, from its simplicity, compactness, and portability, possesses many advantages. Electricity is generated by the friction of two revolving discs of ebonite against two small cushions covered with cat-skin, and is received by two cones, and transmitted by a metallic conductor into the interior of a Leyden jar, from which it is discharged by pressing a button. The apparatus is, however, very delicate; both glass and ebonite being so hygroscopic, that a machine can rarely be depended upon to work many hours consecutively. Unless the places in which it is used, and the rubbers, are dry and warm, the machine will furnish no current, as the electricity is conducted away by the condensed moisture as fast as it is generated.

Magneto-Machines.—These consist of an electro-magnet, between whose poles an armature, wound to a very high resistance, is caused to rapidly revolve by means of crank motion and gearing. An electric current, of high potential, is generated, and at the moment of maximum intensity is sent out to the outside circuit in which are the fuses, the explosion of these being instantly accomplished.

Simultaneous Blasting.—The advantages of firing a number of shots simultaneously, especially in shafts or headings, are self-evident, particularly where machine drills are employed. In the first place, as soon as the machines have been removed and the holes charged, the rock should be shot down as quickly as possible. Then all the shots going off at once assist each other, their force is applied collectively, and the whole of the rock is brought clean away, while if fired separately, each individual blast has to tear out the mass of rock allotted to it, the result being that in the former case less explosive is required, and in addition a minimum amount of time is taken up in the operation. Another advantage of simultaneous firing, is that all the smoke produced by the explosion is generated at one time, and the men only have to wait for this to clear away, while if shots are fired independently, they have to wait after each blast.

FIGS. 74, 75 AND 76.



For firing a large number of shots at once electricity is particularly useful, the reduced quantity of explosive used balancing the cost of the electric fuse, the saving in time, already referred to, remaining as an advantage. Another point of importance is the question of missed shots. When firing with fuse, one can never be sure whether the shot has really missed or only hung fire, and unless explosion takes place the working has to be fenced off for a considerable time, thus entailing a loss; but with electricity, nothing of the sort occurs. After the current has been passed through the wires the place can be approached at once without danger.

For firing by electricity two main systems of connecting the wires to the machines are in use. In the first, the fuses are connected in series—that is to say, one wire of the first hole is connected to one wire of the second hole, and the remaining wire of the second hole to one wire of the third hole, and so on, until all are joined, when there will be one wire of the last hole and one wire of the first hole left unconnected. These are now joined by means of conducting wires, to the machine a considerable distance away in a place of safety (Fig. 74).

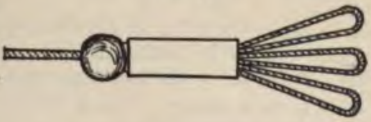
The second system is known as the parallel one. In this, one wire of each shot is connected to one cable, and the other wire to the second (Fig. 75).

Modifications of both these systems are possible, as the holes may be connected in multiple series (Fig. 76).

The disadvantage of the series system, is that the power of the machine has to be equal to that required to fire each fuse, multiplied by the number of fuses, and that unless the fuses have all the same resistance, or vary only within narrow limits, only the most resistant will be fired.

Bickford's Volley Fuse.—To render the operation more simple than with electricity, Messrs. Bickford have designed a method in which ordinary and special fuses are employed for simultaneous blasting. A length of safety fuse is connected to one side of an explosive disc in a tin tube. The required number of special fuses are snugly tied together, their ends cut clean and level, and inserted into the tin tube, touching the other side of the explosive disc. The mouth of the tube is protected by a waterproof substance, such as pitch. To fire, the length of the safety fuse is lighted, this ignites the explosive disc, which starts all the special fuse burning at the same time. The particular point, however, consists of the special fuse, which is manufactured to burn at the rate of 9000 ft. per minute, the speed of ordinary fuse being only 2 ft. per minute. To enable operators to adapt the instantaneous fuse to any available length, to suit their particular requirements, the inventors supply on demand the ignitors with fuse looped as in Fig. 77, so that if the whole length of fuse so looped is, say 10 ft., the miner can cut it into single lengths of 3 ft. and 7 ft., or any proportion of 10 ft. (taking care not to detach it from the ignitor). This does not affect the simultaneousness of the explosion, as, owing to the rapidity of burning, small differences in the lengths of the special fuse are not of any moment.

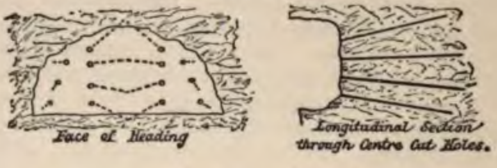
FIG. 77.



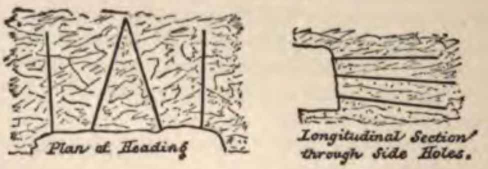
Position of Holes.—The situation and inclination of holes in rock drifts, depends on the nature of the rock, and on the system of drilling employed. With hand drilling and single blasts, everything depends on the skill of the miner, who carefully examines the faces, and decides on the position, direction, and depth of the hole; the conditions that have to be fulfilled being, that the rock should be as free as possible on one side, and that neither too much, nor too little, rock should be attempted to be dislodged. In the former case, if there is too much resistance the hole will act like a cannon, and the tamping will be forced out, producing what is known as a "blown-out shot," while in the latter case the explosives will be wasted.

With machine drills and simultaneous blasting, there is not so much necessity to consider the lines of least resistance, although such is generally done. Many different arrangements can be employed. The following may be considered a typical example.* A wedge, or core, is first blasted out of the centre of the heading, this being known as a centre-cut, the sides being blasted out afterwards. A centre-cut needs about eight holes, divided into two sets, four each, arranged in nearly vertical lines, at equal distances from the centre line of the heading. Each hole of one set of the centre-cut is drilled in a direction intended to meet the corresponding one of the other set at the centre line of the heading, so as to form a wedge. These are drilled fully ten feet deep. Where the character of the material only requires one set of holes in the sides, these are usually three in number, and drilled from seven to nine feet deep. The inclination of the holes in the different sets are shown in Figs. 78–81. The holes inclining upwards, are drilled dry, those horizontal, or inclined downwards, wet. Sometimes second side rounds are required; these will consist of two holes each.

FIGS. 78 AND 79.



FIGS. 80 AND 81.



Blown-out Shots.—The combustion of powder produces large quantities of gaseous products, which, in the case of blown-out shots, are driven violently into the roadways and at the point of discharge act like a piston, driving back the air flowing past the hole in both directions, and producing a partial vacuum, into which the gas contained in the coal is exhausted, and diluted with the air current until the firing point is reached. Clouds of dust may be raised at the same time, and if this mixture comes into contact with flame, a serious explosion is readily produced. It has also been suggested, that the sound wave produced by a blown-out shot, may cause sufficient pulsation in the atmosphere to force flame through an ordinary safety lamp.

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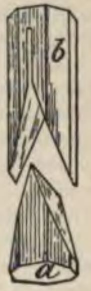
* *The Vosberg Tunnel*, Leo V. Rosenberg, p. 24.

It is, therefore, desirable that blown-out shots should be prevented, care being taken that all the holes are placed in such position that they do the work allotted to them, and bring down the coal. It is most important that the stemming should be unfissured, and adhere closely to the sides of the hole, so that the gaseous products cannot escape before the complete ignition of the powder. To remove, however, any chance of such an occurrence, various tamping plugs have been designed, the majority of which consist of an arrangement of metal wedges tightly secured in the hole, generally by the aid of a screw. They are expensive in first cost and easily lost. A later device is the employment of a cylinder, or rough octagon of pine-wood, with a wedge-shaped piece cut out of it and a saw cut made as a continuation of the wedge-shaped cut. The wedge *a* (Fig. 82) is placed against the charge, the block *b* above it, and the explosion drives the wedge up into the body of the block, and binds it firmly against the sides of the hole.

FIG. 82.

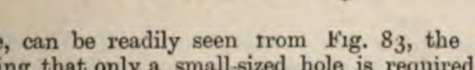


The use of tamping plugs does not seem to afford any greater security than ordinary tamping, if the latter is properly applied.

VARIOUS METHODS TO SUPERSEDE BLASTING.—Numerous methods have been proposed to do away with blasting, the chief of which consists of the application of compound wedges, which may either be driven in by hand or by different mechanical combinations.

Elliott Multiple Wedge.—The construction and method of using these, can be readily seen from Fig. 83, the advantage claimed being that only a small-sized hole is required, and that the weight of the whole apparatus, including boring machine and wedge, is very small, while the expansive force developed is large, owing to the fact that the impact of a blow is more effective than other means of applying wedging power.

FIG. 82.



Haswell Mechanical Coal-getter.[*]—In this machine, the rending action is accomplished by a wedge between two feathers, the wedge being drawn out by a combination of a screw and lever. The bursting action takes place towards the back of the hole, and not at the face where least required.

Burnett's Roller Wedge.—The amount of friction between the sides of the wedge and feathers, in ordinary systems, is very great. To overcome this difficulty, Mr. Burnett[†] has designed a roller wedge, in which rolling is substituted for sliding friction. It consists of two external plugs, or feathers, with an internal wedge running on roller bearings. This wedge is drawn out by the action of a screw and nut, driven by a ratchet and pawl arrangement.

Hydraulic Wedges.—To increase the power of these machines hydraulic pressure has been called into requisition. A man's strength acting on a lever working the piston of a small hydraulic pump, is capable of producing an enormous pressure, which can be applied to driving in wedges. Instead of applying the hydraulic apparatus directly to the wedge, which compels the operator to stand close to the face, in some designs the pressure pump is fixed a considerable distance away, and the water is conveyed to the wedge through a pipe.

Lime Cartridges.—Messrs. Smith and Moore have designed a process for bringing down coal by utilising the expansion of quicklime, when water is applied to it. Ordinary mountain limestone is calcined and ground to a fine powder, and compressed by hydraulic power into a cartridge, having a groove running along its full length. The cartridge is about 5 in. long and 2½ in. diam., and when taken from the press is wrapped in a sheet of paper, and placed in an air-tight box to keep away damp. Coal is holed and shot-holes drilled, in the ordinary way, and cartridges placed in them. An iron tube ½ in. diam., having a small external channel on the upper side, and provided with perforations, is inserted along the full length of the hole. Several cartridges are placed in each hole, the grooves formed in them during the process of manufacture lying against the tube just referred to, and the mouth of the hole is tamped in the usual way. A small force-pump is connected by suitable means, to the end of the tube projecting from the hole, and water forced in. The hand pump is then detached and carried away to another hole. The water acting on the lime greatly expands its bulk, and the coal is forced down.

This system has been employed and given good results at Shipley Colliery for a considerable time, but has not met with much favour elsewhere. It can only be used for certain classes of coal, and great care has to be exercised to keep the cartridges dry.

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[*] N. E. I. xxxiii. 37.

[†] Min. Inst. Scot. viii. 2.

They readily absorb moisture from the atmosphere, and completely lose their efficiency.

Bosseyeuse.—For a considerable length of time an apparatus has been in use at the Marihaye Colliery, Belgium, which consists of a rock drill of the Dubois-François type, boring a series of holes, grouped in a certain pattern, in the face of the work. The drilling tool is removed and replaced by a hammer head, a number of plug and feather wedges are then put in the holes, and driven in by the battering ram, till the rock is broken down and split up. No explosives are used, and trials over a period of many years show that the employment of the machine has not increased the cost of working.

Prohibition of Blasting.—From time to time, suggestions are made that blasting should be prohibited in mines. Undoubtedly, there are seams of coal which can be economically worked by wedges, but such are few and far between. With a seam that is thin, hard, and blocky, and adheres tenaciously to the roof, wedging is of no use, the coal breaks short, and wedge after wedge is inserted with little effect. On the other hand, where the coal is soft, the wedge on expanding simply widens the sides of the bore-hole. As in too many cases the direct causes of explosions can only be conjectured, every cause to which explosions have been traced shares a prejudice which evidently does not rightly belong to them all. Although the occurrence of some explosions can be directly traced to blasting, it must not be assumed that all are due to this cause, or that if it was stopped entirely, they would cease. When a large explosion takes place, the loss of life is so serious that public attention is directed to it, and the other accidents which happen in mines are apt to be lost sight of. Statistics, however, show that the death-rate is higher from several other causes than from explosions; for instance, falls of roofs and sides. Now, with blasting, the men are away from the working face, but with wedging they must be there, and are liable to be injured by falls which take place, especially in thick seams. Wedges are claimed to produce more round coal than when shots are used, but such is not necessarily the case. If the charge employed is properly proportioned, it can be made to do what is required; all that has to be done to produce the coal in a large round state, is to vary the amount of explosive.

To show the increase in cost due to prohibition of blasting, Mr. W. Y. Craig* arranged for the best miners at Podmore Hall Colliery to be employed to work at day wages on two places for one month with, and one month without, powder. In a 12 yd. drift, working one month without powder, the wages paid were £16 0*s.* 10*d.*, quantity produced 233 tons, 11 cwt., 3 qrs., cost per ton 1*s.* 4*d*; same worked with powder, wages £17 9*s.* 3*d.*, including

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* N. Staff. Inst. iv. 53.

CHAPTER V.

SINKING.

Position of Shaft.—The commercial success of collieries depends in a great measure on the position of the shafts, and before deciding on their situation, every point should be given careful consideration. In proved districts where the inclination of the seams is known, the shaft is generally placed in the deepest point, especially where quantities of water are expected, as both water and coal gravitate to the shaft and render haulage easy. Dealing with water in dip-workings is most expensive. It is advisable to place the main shaft somewhere about the centre of the royalty so that equal areas can be worked on all sides of it. Surface considerations may, however, overweigh the majority of the underground points. The disposal of the produce must be carried on easily and cheaply; proximity to towns or places where a household trade can be carried on is important. Communication with railways or waterways should be studied. A supply of water for boilers, &c., is requisite, many collieries labouring under great cost and disadvantages through being unable to obtain this. In unexplored districts, it is well not to make the first shaft a principal one, but to sink it down to the seams, and after proving their inclination, &c., to decide on the position of the main winding-shaft, from data so obtained.

Form of Shaft.—At the present time, so far as European practice is concerned (except in Scotland), the general custom of colliery districts is to make shafts circular. Various other shapes have been tried—square, elliptical, and polygonal—but have been abandoned in the majority of cases. In order to economise space, many of the earlier shafts were made rectangular, and are still often so sunk in Scotland, and in the United States, but it has been found that round shafts are easier and cheaper to sink, more capable of resisting the pressure of "heavy" strata, absolutely necessary in running ground (the pressure being equalised), and more suitable for the application of metal tubbing. The waste of space and other disadvantages due to circular form are less considerable than had been supposed; indeed, by careful arrangements the space wasted may become almost nothing. The ventilation of large coal-mines could not be well carried out with rectangular shafts, as the running of the cages would interfere too much with the passage of the air; indeed the space unoccupied by the cages is a positive advantage in numberless instances.

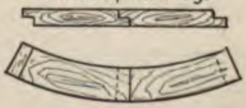
Where stone, bricks, or iron are cheap, the circular form is preferred, but where wood is abundant and largely employed for securing the sides, and other material absent, the rectangular shape is adopted.

Size of Shaft.—This depends entirely on the size of tub employed and on the output required. After deciding on what daily quantity is to be extracted, and the weight that each tub shall contain, the number of tubs to be drawn each day and each hour can be obtained. Knowing the depth of the shaft, the speed at which winding is to take place, and the time occupied in changing the tubs on the cage, and allowing a margin for interruptions, the number of tubs to be raised at each lift is easily found. Then after deciding how many decks or platforms there are to be in the cage, the number of tubs on each deck is established. As the tubs have to be of a certain size to hold the quantity they have to contain, the number on each deck determines the size of the cage. If the shaft is only to have one cage working in it, its diameter must be such as will allow a rectangle of the size of the cage to pass through freely, allowing a margin for clearance of from three to six inches at the corners. If two cages are to be employed, two rectangles should be plotted on paper, with a clearance space between of from nine to fifteen inches, and a circle inscribed round them, allowing a similar space as before for clearance at corners. The diameter of this circle gives the size of the shaft.

Where pumps are required and have to be placed in the winding shaft, the room they take up must also be allowed for. The better plan is, however, to keep everything except winding appliances out of the main shaft.

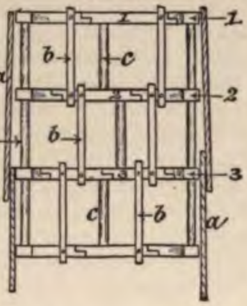
OPERATION OF GETTING DOWN TO THE "STONE-HEAD."—The first operation in sinking, is to get down to solid regular strata, technically called the "stone-head." In the majority of instances, some drift or loose deposits have to be passed through before firm ground is reached, and a foundation obtained for the masonry, or other means which are to be employed for permanently securing the sides of the excavation. Often this preliminary operation is very troublesome and expensive, depending entirely on the nature of the strata.

FIGS. 84 AND 85.



(*a*) **Where the ground is moderately hard** it is usual to first dig down a few feet and then place at the bottom of the excavation a circular frame of timber called a "crib" or "curb." This consists of an annulus divided into a number of segments having joints (Figs. 84 and 85); with narrow curbs, the segments are usually connected together by one bolt, but in broader ones, two will be employed. At the surface, a square frame is formed by four pieces of timber intersecting each other, held by notches where they cross, and with the ends projecting to some distance beyond. This is often held down by pegs which give it a grip on the ground. Timber laggings will now be driven *behind* the curbs, at necessary points where the nature of the ground requires them for support, and the two frames are then connected by nailing on strips of stronger planks (called "stringing deals") at intervals round the shaft on the inside; in addition, short vertical struts called punch props are placed between the curbs to keep them in position (*c*, Fig. 86). Then the ground is removed for a further distance down, a third frame put in, lagged behind, and hung by a further set of planks from the second curb (Fig. 86, *1*, *2*, *3*, are the curbs, *a a* the laggings, *b b* the stringing deals).

FIG. 86.

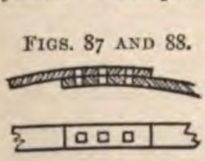


Instead of timber laggings, the space between the curbs is often filled in with a dry walling of bricks called "back casing," the curbs being hung from each other by stringing deals as before.

If the ground is soft and does not afford sufficient support for the curb at the bottom of the excavation, the whole structure is hung by chains or iron bolts from strong baulks of timber placed transversely across the shaft at the surface. These tie-bolts are added to, and lengthened, as additional curbs are fixed below until the firm ground is reached.

Instead of employing wooden curbs for timbering through loose ground, the practice is becoming general of using iron "binding" rings. Four of these go round the circumference of the shaft outside brickwork, and are made of flat strip iron about 3 in. by $\frac{3}{4}$ in. They are connected together by bolts, each segment overlapping at the joints. When placed in position laggings are driven down between them and the sides of the excavation. By arranging a number of bolt-holes in each segment (Figs. 87 and 88) they can be made to overlap each other more or less as desired, and thus fit a smaller or larger excavation if necessary.

FIGS. 87 AND 88.



The permanent lining is then put in by one of the methods described further on, care being taken that all the temporary timbering is removed.

(*b*) **Where the ground is loose**, different methods to the foregoing have to be employed. Sinking through quicksands and heavily watered beds, is one of the most costly operations connected with mining, and calls forth all the skill and experience of engineers. The means used for reaching the "stone-head" where quicksands are present, depend in a great measure on the thickness that has to be passed through.

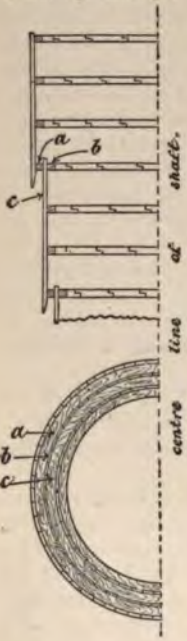
(1) *Pile-Driving.*—At one time the general method adopted was by what is known as "piling," which consists of driving vertically downwards, all around the circumference of the shaft, wooden planks with their edges touching each other, and supporting them internally with curbs. The planks or piles used are generally from ten to fifteen feet long, six inches broad, and three inches thick, having their lower end tapered off to a cutting edge, and their upper one strengthened with a wrought-iron hoop, so that they are not split by the blows of the wooden driving maul. In forming the cutting edge, all the taper is given on the inside, the outer side not being touched, as if it was cut to a **V** form the piles could not well be driven down vertically, as the tendency would be for them to incline towards the centre of the shaft. In hard ground, the cutting ends of the planks are shod with iron to enable them to penetrate more easily.

The width of the supporting curbs depends on the size of the excavation. They are, however, generally made about six inches broad, and placed at closer vertical distances in large shafts than in smaller ones.

When the bottom of the first length of piles has been reached, and a curb placed round as a support, a second set are driven down *inside* the lower supporting curb, so that the diameter of the shaft is reduced in that length by twice the thickness of the laggings and twice the breadth of the curb, or, if 6 in. curbs and 3 in. piles are used, by 18 inches. As this reduction takes place with each course of piles, the shaft has to be commenced at the surface with a diameter sufficiently large to allow it. It therefore becomes necessary that the thickness of the quicksand to be passed through should be approximately known, such being usually found by boring. If piles 15 feet long are used, a fresh course will have to be put in about every twelve feet, therefore if the quicksand is 60 ft. thick, five reductions will take place, altogether amounting to $5 \times 1\frac{1}{2} = 7\frac{1}{2}$ ft. If a 15 ft. shaft is being sunk with brickwork lining 18 in. thick, the diameter at the bottom of quicksand must be at least 18 ft., and at the surface the excavation will require to be $18 + 7\frac{1}{2} = 25\frac{1}{2}$ ft. diameter.

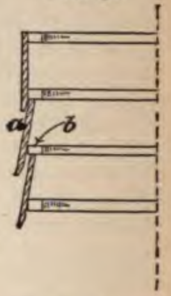
Commencing at the surface, the ground is excavated as far as it will stand, and the first curb carefully laid down, with its centre coinciding with the centre of the shaft; the lining of piles is then driven down as far as possible, and the ground taken out on the inside till a sufficient distance has been sunk to require the support of another curb, which is accordingly placed in position. The piles will then be driven down a further distance, more ground excavated, and so on until the bottom of the first set of piles is nearly reached. A supporting curb (*a*, Figs. 89 and 90) will then be fixed against the piles and a second one *b*, 18 in. less in diameter, will be placed inside it, leaving an angular space of 3 in. between the two. A second set of laggings, *c*, will now be driven down in the space left between the two curbs, and the same cycle of operations gone through as before. This process is repeated until the solid ground is reached.

FIGS. 89 AND 90.



The method just described is the one generally adopted in the North of England, and where the ground is very loose and of a watery description. Sometimes, however, instead of driving down the piles vertically they are inclined outwards (*a*, Fig. 91), and then as the ground is excavated towards their lower end, the pressure gradually drives them forward. When the ground has been got out for a short distance in the bottom, supporting curbs *b* are fixed in the same manner as before. As the piles in this instance do not touch each other at their lower ends, straw, or similar material, is pushed between the joints, to prevent the sand from flowing into the shaft.

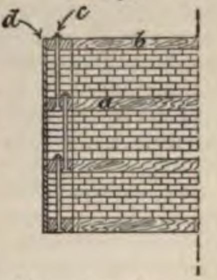
FIG. 91.



When the ground is very loose, or watery, the difficulty of using the latter class of piling is surmounted by the so-called method of "quartering," in which only a portion of the circumference is attacked at a time. Commencing from the upper curb, ground is taken out for a depth of 3 ft. in the centre of shaft, piles 4 ft. long are driven down for a length of about 8 ft. round the circumference of the shaft, and when each has gone in its full length, the top end is knocked back under the curb. The ground is got out for a length of 3 ft. in front of the piles, a segment of a curb laid on the bottom perpendicularly under the upper one, and the space between filled in with dry brickwork; when this is completed the two curbs are connected by nailing on stringing deals, and a further series of piles driven down at the end of those already in position. Sufficient ground is then excavated in front of the piles, until room is obtained for another segment of the curb, this joining up to the first one laid. The space between this and the upper curb is then filled in with dry brickwork as before, more piles driven down, the ground excavated, a third segment laid, and the process repeated, segment after segment being "quartered" in, until the whole circumference is firmly secured for the length under consideration. A lower length is then attacked in a similar manner, and then another, and so on until solid ground is reached.

(2) *Drums.*—The method of pile-driving is an exceedingly expensive one, and is often superseded by one of the so-called "drum" methods. In this system, a drum either of wood or iron of a diameter sufficiently large to allow the permanent walling being inserted inside it, is sunk through the sand.

FIG. 92.



(*a*) *Wood.*—A curb (Fig. 92), 14 or 18 in. broad by 6 in thick, is first laid truly level on the top of the bed to be sunk through, and a tier of masonry built on it to a height of about 3 ft., when a second curb will be laid, and connected to the first by iron tie-bolts passing through the brickwork. In order to prevent the dislocation of the masonry, and to reduce friction during descent, a close lining of planks is nailed around the outer circumference, these being planed at the edges where they meet, to ensure a water-tight joint. A further length of masonry is then built on the second curb, a third one laid and connected with bolts, and laggings placed round the outer circumference, as before. In Fig. 92, *a* and *b* are curbs, *c* a wrought-iron connecting bolt, and *d* the lagging planks. Where the ground is of loose description, the weight causes this drum to sink, but if the beds are more coherent, the bottom curb is provided with a cutting edge, either by bevelling off the inside, or by attaching an iron shoe. Opinions differ as to the advisability of employing cutters at all, it being contended that they are merely a source of weakness, as when any exceptionally hard substances are met, the tendency is to turn the cutter outwards, and often rupture the drum. The ground in the centre of the shaft is then slowly removed, and the cylinder sinks. A man stands on the drum with a straight edge and level, and gives directions as to where material is to be excavated if one side "hangs" behind, but care is taken not to remove any ground near the curb for fear the drum should suddenly sink, and "cant" over.

When the drum has sunk, say a distance of 3 ft., more brickwork and another curb will be added at the top, and connected to the others by bolts as before. This is repeated every time the drum sinks the certain specified distance, until, in the course of time, the solid ground is reached.

The great difficulty encountered in sinking by this operation is in keeping the drum truly vertical. Constant supervision and care must be exercised to prevent "canting." As a matter of fact, the drum never goes down regularly, but does so by fits and starts, sometimes falling through five or six inches at a time. With each such movement, cross-staffs are placed on the curbs, and a spirit level applied, to see if the apparatus is horizontal. If it is not, either a small quantity of ground is taken away from beneath the highest part, or additional weights are added to the drum on that side.

(*b*) *Iron Drums.*—The objection to wood drums is, that they require nearly as large an excavation as if piling was employed, for often, after getting down some distance, the whole structure sticks, and cannot be moved. A second one has then to be sunk telescope fashion inside the first. To get over this, wrought or cast iron drums are used, as although they sometimes have to be telescoped one within the other, comparatively little space is lost. With cast iron ones, the circle is composed of a certain number of segments, varying from 4 to 5 feet long by 2 feet deep, strengthened by vertical and horizontal ribs, similar to Fig. 115. As these strengthening ribs are on the *inside*, the outside surface is smooth, and meets with little resistance in passing through the ground. The joints between the different segments are made with sheet lead and bolts, and a cutting edge is attached to the bottom segment. The procedure is very similar to that with brick drums. They are usually weighted, and to make this more easy to carry out, the ribs are made broader. If sufficient weight cannot be applied by placing material on these ribs, two sets of timber buntons are placed across at right angles to each other, and a platform laid on them, upon which any amount of débris can be placed, a passage being left through the centre for the workmen to reach the bottom of the cylinder.

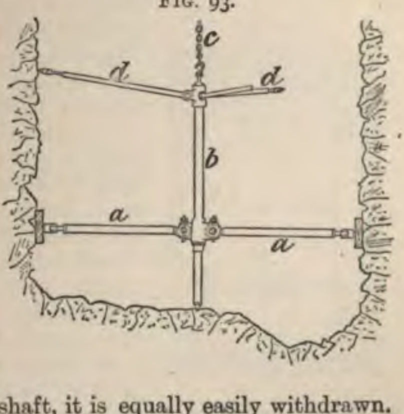
On the other hand, it often happens in very watery ground, that the drum has a tendency to sink too fast, and, unfortunately, not to do this equally, but to get lower on one side than the other, and as this is a point which it is particularly desirable to prevent, the tubbing is hung at four points by a chain and lowering-screw arrangement from strong transverse beams at the surface. Where such means are employed, the tubbing is easily kept perpendicular, as, even if the sand is watery on one side, or boulder-stones cause an obstruction, it is only necessary not to let out a screw on the side which requires checking. Instead of cast-iron drums, which are liable to break, owing to the unequal strain to which they are subjected, wrought iron ones are sometimes employed.

Comparing the two systems, there is little doubt that, where the thickness of ground to be passed through is large, the iron drum possesses certain advantages, as by its use a smaller excavation is necessary; its sides do not offer such a resistance in passing through the strata, and the time of sinking is less, owing to the ready way in which the various parts are put together and added to; but unfortunately it often breaks, which occasions months of delay, and increases the cost of sinking. This is the only advantage possessed by wooden drums; instances are to be found where such have been pushed into an oval form, and yet have not collapsed.

When the sinking has reached the stone-head, no matter what system has been used, the procedure afterwards is always of a similar character. The ground is carefully prepared for the seating of a curb upon which the permanent lining is brought up to the surface by one of the methods to be described further on, all temporary timbering being removed as the work comes upwards. As a matter of fact, the lining is usually carried a short distance above the surface of the surrounding ground to secure some "tip" for the débris which is excavated from the sinking.

METHOD OF PROCEEDING AFTERWARDS.—On reaching the solid ground, excavation proceeds with the tools described in the previous chapter, those employed depending entirely on the nature of the strata which have to be passed through. Several difficulties are encountered where machine drills are employed. Owing to the uneven nature of the bottom, the ordinary tripod stand is used with difficulty, taking from 5 to 10 minutes to fix, and then the legs move during drilling if the ground is soft. As no roof exists, the vertical stretcher bar has to be replaced by a horizontal one. This is not easy to fix, and takes so much time to adjust, that often, instead of moving the bar and drilling holes in the most favourable position for blowing, they are put down in such places as suit the drill, and consequently are not so effective. Considerable time is also lost in raising drills and bars out of the way when blasting takes place.

FIG. 93.



To obviate these disadvantages a boring frame is employed consisting of 4 main stretcher bars *a a* (Fig. 93), hinged to a central support, *b*, and suspended by a chain, *c*, and capstan rope. Each of these bars is provided with a lengthening screw and claw, so that the whole structure can be readily clamped in position, and as it shuts up when not fixed against the side of the shaft, it is equally easily withdrawn. To keep the structure from lifting by the impact of the drills when boring, four secondary arms, *d d*, are arranged near the

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top of the frame, these being strutted against the sides at a slight inclination upwards. If the drills are mounted on swinging arms (see Fig. 62) they can be placed at any angle and clamped in any position, and the holes put in anywhere.

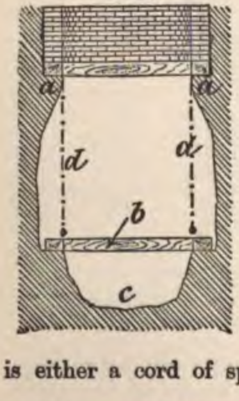
Where drills are adopted, the general procedure is to first bore all the holes required, hoist up the frame and drills with an engine, fire the holes simultaneously, and then load up the débris until the bottom is clear, when the drills are again lowered and fixed, and drilling recommenced. In hard ground, probably only one set of holes will be bored and blasted and the rock removed in 24 hours.

Another practice gaining ground, is to lower the walling stage to about 8 or 10 feet from the bottom, wedge it there and form an artificial roof, and then use ordinary vertical stretcher bars.

Another method proposed, and indeed, tried in two instances, is to start at the surface and bore a series of holes 200 or 300 feet deep with the aid of diamond drill, and fill them up with sand. Blasting then commences by removing 4 or 5 feet of sand from the holes, and firing them in groups, this process being repeated until the bottom of the holes is reached, when the drills are again introduced, and a further distance bored. The Pottsville shaft, U.S.A., was sunk in this manner,* 25 holes being bored 1$\frac{3}{4}$ in. in diameter about 3 ft. 3 in. apart in one direction, and 4 ft. in the other. The central group of holes was always fired first, and the outside rows afterwards. The process was expeditious, but the financial result does not appear to be satisfactory. At Harris Navigation Colliery, the same method was tried for about 70 yards but abandoned.

With the object of providing support for the curb carrying the upper length of lining, when sinking recommences, the excavation is carried down for about 3 to 5 ft., lineable with the *inside* of the curb (*a*, Fig. 94), then shorn back until the diameter is large enough to take in the permanent lining, and afterwards carried downwards this size, until the strata require more support than temporary timbering affords. A seating will then be made for a curb *b*, leaving a space *c* in the bottom of the shaft for the collection of water, &c., and the walling built on it up to the curb above, the ground *a* being removed for this purpose, not all at once, but in sections.

FIG. 94.



Keeping the Shaft Vertical.—This is done by the aid of a centre line which is either a cord of special manufacture about $\frac{3}{8}$ in. in diameter, or preferably a copper wire, long enough to reach from the surface to the bottom of the shaft when completed. One end of this line is coiled on a small drum situated near the top of the pit, and the other end is led by pulleys to the exact centre of the shaft. As a rule, the central point is a hole bored through a baulk of timber placed across the shaft, but the best plan is to provide a hinged arm (*a*, Fig. 95) built firmly into the masonry. When in use this is kept in its proper position by the stop *b*, but if not, it is folded upwards into the position shown by dotted lines at *c*. After the line has been passed through the centre hole, a link is attached, from which a weight can be hung, this dipping into a bucket of water at the bottom, so that the line is steadied. As soon as the proof has been made the weight is removed, and the cord wound up again on the drum.

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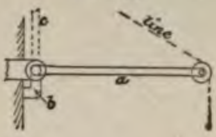
* *A New Method of Sinking Shafts.* E. B. Coxe. Amer. Inst. M. E. i. 261.

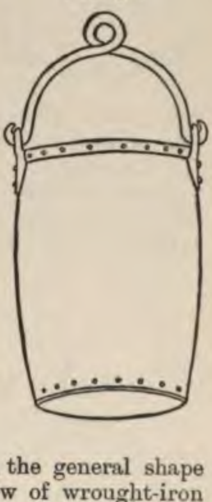
FIG. 95.



For determining whether sufficient ground is removed, the master-sinker is provided with a "centre" staff, which is a wooden rod about $1\frac{1}{4}$ in. square, and equal in length to the outside *radius* of brickwork. This is moved round the central point as excavation continues.

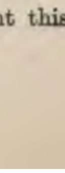
For setting out the curbs exactly beneath each other a series of cords (*d*, Fig. 94) are hung all round the circumference of the shaft at intervals of about 3 ft. These are attached to the inside of the upper curb, and serve, not only to set the curb below, but also as a guide for the amount of excavation. Every third curb will be checked by the main centre line, the intermediate ones being set out by the side lines.

FIG. 96.



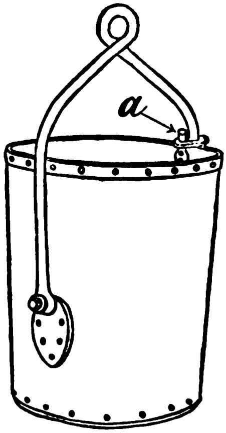
Winding Débris.—The material excavated is brought to the surface in wrought-iron barrels called kibbles, hoppits, or bowks, the general shape being shown in Fig. 96. At the top is a bow of wrought-iron swung to the body by two eye-pieces riveted to the sides of the kibble. Attachment is made to the winding rope through a spring hook (Fig. 97). With such construction time is lost at the surface, as the full bowk has to be taken from the rope and replaced by an empty one. For this reason the tipping kibble is preferred. Its body is similar to the one already figured, but the wrought-iron bow is not attached at the top but at a point below the centre of gravity, so that when full, the tendency is for the kibble to turn over and empty itself. To prevent this

FIG. 97.



happening during hoisting, a short vertical pin (*a*, Fig. 98) is riveted to the inside of the bucket, and an ordinary chain link, sliding on one of the arms of the bow, passed over it. On reaching the surface this safety link is lifted off the pin, when the hoppit immediately turns over and empties itself. With such a system the kibble is only removed from the rope at the bottom of the shaft, one disconnecting being saved.

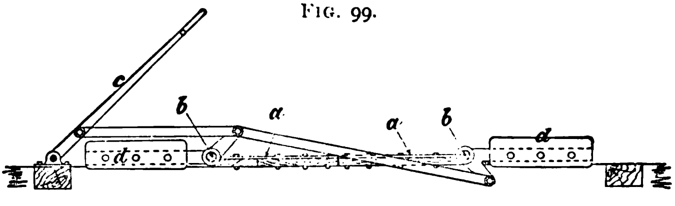
FIG. 98.



Covering over Pit Top.—This was originally done by means of a travelling platform, which could be wheeled over the shaft when the kibble reached the surface, and removed again when descent had to be made. The labour here is considerable, and time is lost. To get over these drawbacks two hinged doors, with their weight counter-balanced, are adopted. These when open, form a fence protecting the pit top on two sides; the other two are guarded with a permanent fence. When these are down, they entirely close the opening, and two rails on the upper side of each door form a continuation of the tramway going to the dirt heap.

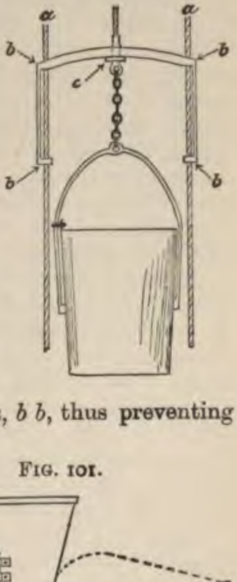
Even, however, with these a little time is lost as each door has to be lifted separately; so, to remove this complaint, Mr. Wm. Galloway has designed an arrangement of levers and counterbalances (Fig. 99), by means of which both are opened at the same time. Two hinges, *a a*, are bolted to each door, and keyed on cross shafts, *b b*, to which, by means of a handle, *c*, and connecting links, a movement of rotation can be given, and as the hinges are fixed to the cross shafts, the doors lift when the latter turn. The weight of the doors is counterbalanced by four blocks of metal, *d*, so that they will stand at any position in which they are placed.

FIG. 99.



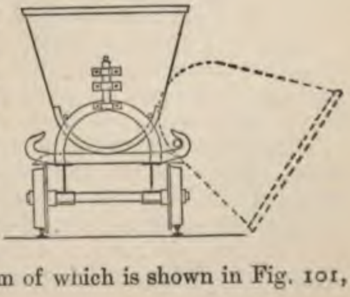
Guides.—The introduction of guides in sinking pits is desirable to prevent the oscillation of the kibble, which gets especially large in deep undertakings, considerable time being lost in steadying it before winding commences. Two methods are adopted, in the first a single guide rope is passed down the centre of the shaft, while in the other two ropes are used. In each system these guides, which are of flexible wire, are coiled on a drum worked by a capstan engine at the surface, and can be lengthened as the sinking proceeds, and also form the means by which the walling stage is raised during bricking operations. In the former, however (see description, p. 124), the walling stage is removed during sinking, and the kibble is guided to the bottom of the shaft; while in the latter, one end of each guide is always attached to the walling stage which remains in the shaft during sinking, and the kibble is only guided to the point where the walling stage is suspended. Each system has its advantages, as with one central rope the kibble is guided all the way, and if a heavy weight be hung at its lower end, the centre line of shaft is obtained without any further trouble, while in the two-rope system walling can proceed while sinking is going on below, thus saving considerable time, an advantage not possessed by the other method.

FIG. 100.



The system of employing two guides was patented by Mr. Wm. Galloway in 1875. In it, two wire ropes (*a a*, Fig. 100) are connected at their lower end to the walling stage, and pass over two pulleys on the headgear to drums worked by a steam crab, each drum being able to be moved independently, to provide for any casual irregularity in the length of guides. An iron frame, consisting of two legs joined together by a cross-bar, called the "rider," clasps the two guides loosely at four points, *b b*, thus preventing any chance of cross-binding. The winding rope passes through a hole in the centre of the rider. The capping connecting the winding rope and chain going to the kibble, is provided with a buffer, *c*, consisting of alternate layers of india-rubber and sheet iron, which are of larger diameter than the hole in the rider cross-bar, and therefore cannot pass through it. When the kibble arrives at the surface the balanced doors are closed, a tipping waggon (one form of which is shown in Fig. 101,

FIG. 101.



the sketch explaining itself) run beneath, and the kibble emptied into it. The waggon is then removed, the doors opened, and the bucket and rider lowered away, until the walling stage is reached, when the arms of the rider are caught by two buffers on the bridle chains. The kibble and winding rope continue their descent, passing through the square opening in the stage until the bottom of the shaft is reached. In ascending, the winding rope slides through the central opening in the rider cross-bar, until the buffer on the capping comes in contact with it. The rider is then lifted to the surface.

In sinking the Harris Navigation shafts, the time occupied in winding, changing, &c., before adopting guides, was 4 min. 49 sec. from a depth of 475 yds., whereas after the guides were put in, the time fell to 3 min. 26 sec. from a depth of 530 yds.*

LINING SHAFTS.—In describing the operation of getting down to the stone-head, both timber and iron were alluded to as being employed for securing the sides of the excavation, only as a temporary means. As soon as this point is reached, some other method of a more permanent character is adopted. Several substances are employed for permanent lining under ordinary circumstances, such as wood, stone, or brickwork, but except in cases where the two former are plentiful and cheap, they are rarely used. Bricks are plentiful in most colliery districts, and in the great majority of instances are adopted. Sometimes they are moulded to the shape of the shaft, and when such is done the labour of laying them is reduced, and the joints are well made, but in large shafts, where the curvature is small, ordinary 9 in. bricks are generally employed as they are much cheaper.

Bricks.—For all mining purposes, the bricks used should be good hard burnt ones, and free from cracks and stones. The clay of which they are composed, should be rich in alumina, and thoroughly ground in a pug-mill; they should also emit a ringing sound when struck. The surface should not be too smooth, a probable result of over-burning, or the mortar does not readily adhere to them. When made by machines in which wires are used for cutting the blocks of clay into the required shape, the edges are left rough and this instead of being a disadvantage really assists the brick in laying hold of the mortar.

Number of Bricks required.—The easiest way to find out how many bricks are required for walling, is to calculate the cubic contents of masonry for each yard in depth, and then multiply by the total depth.

If D = the outside diam. of brickwork in ft. and d the inside diam., $(D^2 - d^2) \times .7854$ will give the area in sq. ft. of the annular ring; this multiplied by 3 (number of ft. in yd.) and divided by 27 (cub. feet in cub. yard) gives the number of cub. yards of masonry for each yard of depth, or simpler still, divide at once by $\frac{27}{3} = 9$. Ordinary bricks are $9 \times 4\frac{1}{2} \times 3$ inches, so that a cub. yd. of masonry would contain $4 \times 8 \times 12 = 384$, if mortar was absent. As this occupies a certain space it is usual to consider in practice that 1000 bricks will build 3 cubic yards.

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* Inst. C. E. lxiv. 26.

Mortar. – The mortar used is generally composed of lime and sand, and should be of a slightly hydraulic character. The ingredients whatever they may be, are usually mixed in a mortar mill, which not only considerably reduces the labour of production, but also the cost, as with it all rough parts are ground up, and no refuse is left, as there would otherwise be if ordinary hand-made mortar was employed. As a substitute for sand, clinker-ashes from underneath boilers are largely employed with most satisfactory results, as they give ordinary lime somewhat of an hydraulic character, and the mortar sets very much quicker and harder, than when sand is used. It is, however, very necessary that these ashes should be free from the finer or smaller parts. As they are a waste product at collieries, considerable economy results from their use. Where the strata are wet, and the brickwork has to resist the passage of moisture, cement is often used, either by itself, or mixed and ground up with lime. Where cement is adopted, it should be used as quickly as it is made, if not, it partially sets, and has to be broken up, and made over again. Thus, not only is time lost, but the cement sets neither so well nor so quickly on the second operation, and the strength is materially reduced.

Whatever quality of mortar is employed, too much must not be used, as it is not so good for resisting pressure or the passage of water as a brick. The proper thing to do is to lay a bed of mortar, and not place the brick in its proper position, but drop it down a few inches away, and then rub it towards the place at which it is to be fixed. When the bricks are of a close-grained character they absorb moisture so quickly from the mortar, that the mixture dries before it is properly set, so, to prevent this, it is usual before laying such bricks to soak them in water.

Thickness of Brickwork.—The thickness of walling depends entirely on the diameter of the shaft and the nature of the strata. If it is coherent rock a single brick is used, more as a preventive of weathering action than as an actual support. In looser ground, brickwork from 14 to 22 in. thick is put in. Opinions differ as to whether brickwork in shafts should be made solid, that is to say, whether it should be carried up to the limits of the excavation, or whether it should be finished off at a certain distance, and some looser substance interposed between it and the strata. The author's experience is decidedly in favour of the latter. Where the brickwork is made to abut against the rocks, and heaving takes place, it is either bulged or broken, but if, on the other hand, some soft packing substance is interposed between the sides of the rock and the brickwork in the shaft, the first result of pressure is to compress and tighten this loose material. If any heaving takes place at one point, all the pressure is not thrown on the brickwork opposite to it, but, owing to the soft compressible stuff being interposed between, is distributed over a larger extent of surface. At the same time, it should be pointed out that no spaces or cavities should be left between the brickwork and the sides of the shaft, but every opening carefully filled in with loose, fine material. Coke dust or well-burnt small ashes are excellent for such use, and often the small dust from stone-breaking machines, where such can be obtained, is employed. Sand is too heavy for shaft work.

Ordinary Curbs.—The brickwork is put in in sections, each length being supported on curbs. Wooden curbs are generally employed, similar to those already described, but as they decay somewhat readily, cast iron ones are often substituted. A curb of this material employed in a shaft 19 ft. diam. is shown in Fig. 102. It is 10 in. broad by 4 in. wide by ¾ in. thick. Ten segments form the circle, and each one is strengthened by two ribs. Two holes are left in the transverse ribs at each end, through which bolts are passed to connect the segments together.

FIG. 102.

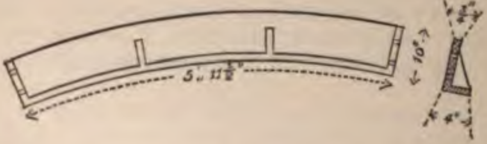
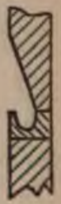


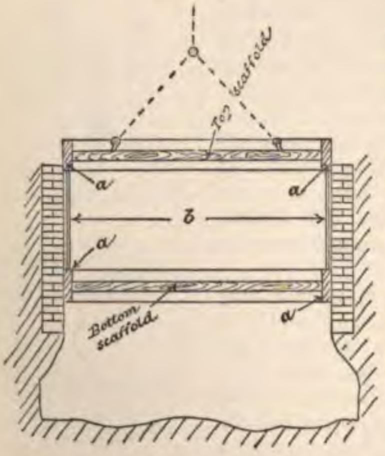
FIG. 103.



Water Rings.—If the strata are at all wet, more or less moisture always percolates through the masonry, and is collected in what are called "water rings" or "garland curbs," from whence it is conducted down the shaft in tubes. The ordinary construction of water ring consists of an iron curb cast with a hollow groove. These are bedded as usual, but the brickwork for a short distance above, is shorn back (Fig. 103), so that the water readily passes into the groove.

A superior construction for larger quantities of water is illustrated in Figs. 104 and 105. For a few courses the brickwork is made solid, and an ordinary curb *a* fixed in position. All the joints in the curb and between it and the brickwork are made with tarred flannel, and the space behind the curb is well rammed with puddled clay. Two courses of brickwork *b* are laid, but are set back from the rest of the work as figured. A shrouding, *c*, this iron frame. The lower frame consists of four pieces of angle-iron, d^1 d^2, crossing each other at right angles, a circular band of angle-iron in three segments, and a straight piece of angle iron joined to the short ends of d^2 and to the ends of the circular frame as illustrated. The object of the latter piece is to enable the hinged door, *h*, to be placed in the part forming the smaller segment of the circle. When the stage is taken past the pipe buntons the door is raised up. Four upright pieces of angle iron connect the upper frame and the lower one, and four plates of sheet-iron, attached to the four uprights, form the fence around the central opening in the stage. The roof is 10 ft. 6 in. above the stage proper. It is formed similar to the floor, but is of rather smaller diameter, and is covered with sheet-iron. An iron ladder, *m*, provides a means of access from one stage to the other. The whole structure weighs about five tons, and is suspended from the guide ropes, *n n*, which are 5 ft. 6 in. apart from centre to centre. In the No. 2 shaft the details have been altered somewhat, two openings being provided, as two kibbles are employed for winding purposes. In this instance, suspension is made by two ropes, which serve the purpose of four guides, by the following attachment: The end of *each* suspension rope is attached to a strong screw in the pit-head pulley, and passes downwards to the walling stage, then round a small pulley fixed on it, proceeds a short distance across the stage, round another pulley similar to the first, then vertically up the shaft, and over another pulley on the pit-head frame, finally going to the drum of the capstan engine.

FIG. 108.



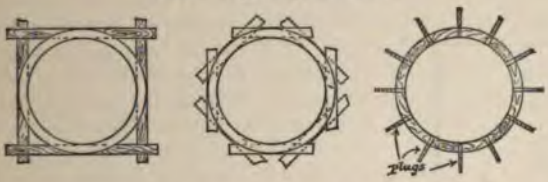
A model of a similar appliance was exhibited by the Roche la Molière Company at the Paris Exhibition. It consisted of an iron ring from 25 to 39 in. deep (*a*, Fig. 108) of the exact diameter of the finished shaft, suspended from bridle chains. A similar ring was hung about 10 ft. below, and the two connected together by a series of iron rods. These two rings support two scaffolds, on the upper one of which the men stand to do the bricking. The bricks, &c., are placed round in contact with the upper ring, the platform slowly raised, and another tier of masonry placed in position.

In this way, the time usually spent in measuring the diameter and ascertaining the verticality of the shaft is saved, the top ring being kept a few courses above the brickwork to give a guide to the masons, the object of the two rings evidently being to keep the scaffold in a vertical line. Where the spaces between the masonry and the sides of the shaft are to be filled in with cement, &c., deeper rings are employed, so that more of their height might be left below as a support until the cement sets.

Supporting Curbs.—It often happens that when the sinking is passing through rotten ground, lengths of walling are required to be put in to secure the sides, but suitable places cannot be found on which to seat the curbs. In such cases the difficulty is got over by one of two methods, either by putting in what are called "square frames," or by supporting the curb on a series of iron plugs driven in all round the circumference of the shaft.

A square frame, with its sides equal to the diameter of the shaft, is placed at the point where the walling is to commence, and as the corners of this frame project a considerable distance beyond the circumference of the pit (Fig. 109), sufficient support is afforded to the curb. In large shafts the amount of ground to be excavated for a square, having its sides equal to the diameter of the pit, would be so great that the cost would be a serious matter, so to remove the difficulty, and yet obtain some support, the square is replaced by an octagon (Fig. 110).

FIGS. 109, 110, AND 111.



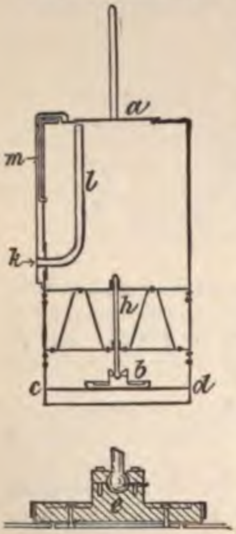
The better method is to bore a series of holes, 2 in. diam. and 3 to 4 ft. apart, around the circumference of the pit, to a depth of 3 to 4 ft., depending on the strength of the ground. These must be on a truly horizontal plane, and wrought-iron or steel plugs are firmly driven into them, leaving a projecting portion upon which the curb is bedded (Fig 111).

Ventilation.—This is usually done by laying a line of sheet-iron pipes from 15 to 20 in. diam. down the side of the shaft, and connecting them with a small blowing fan at the surface. These pipes are held in position by dog-hooks driven firmly into the masonry.

Lighting.—In districts liable to sudden outbursts of gas, the same precautions have to be adopted in sinking as in ordinary working, and safety lamps are employed, but these give a very imperfect light in a downwards direction, where the sinker wants it most particularly. Of later years the electric light has been employed, with most satisfactory results, as, owing to the clear light given, the men do a great deal more work. A cluster of incandescent lamps, protected by a glass globe, is generally employed, this being suspended from a cable, which is wound on a drum at the surface, and which gives a ready means of raising or lowering the lamps, either to give more light, or to remove them out of danger when shots are being fired.

Dealing with Water.—The presence of a small amount of water largely increases the cost of sinking. A small quantity is got rid of by baling with a bucket into a tipping barrel, similar to the tipping kibble, and then winding it to the surface. This is a very slow and costly procedure, and where the quantity is at all large, one of the different classes of pumps will have to be employed. These are described in the chapter on pumping.

FIGS. 112 AND 113.



To save the time and cost of baling, Mr. Galloway has designed a pneumatic water tank, which consists of a cylindrical barrel, 4 ft. 2 in. diam. and 8 ft. high, closed at the top in which there is a door (*a*, Fig. 112) bolted to the cover, this giving access to the interior when necessary; the bottom, *c d*, is 5 in. above the base of the cylinder, and has a central opening 18 in. diam. for the valve seat which is turned in a lathe. The valve *b* consists of a block of cast iron, *e* (Fig. 113), having its lower face turned true, and over which a sheet of leather is tightly capped. A circular plate of iron, 16 in. diam., is bolted to this valve, by bolts having countersunk heads, as shown in Fig. 113. A spindle, *h*, working through two guides, having a turned ball in its lower end, is held loosely in a socket in the valve, as shown, by which means the vertical movement of the valve is secured, while the ball-and-socket joint enables it to readily accommodate itself to the seat in any position in which it may be turned.

At *k* is one half of an instantaneous coupling, supplied by the Vacuum Brake Co., constituting the outer end of the pipe *l*, which passes through the side of the cylinder, and rises to within 1 in. of the top of the barrel. A glass gauge, *m*, shows the height of water in the tank, this being protected from chance blows by strong ribs of angle iron.

Vacuum is created by air pumps at the surface, and is equivalent to 20–22 in. of mercury; 3 in. pipes are carried down the pit and connected to 30 ft. of flexible hose, having a stop-cock and a corresponding half of an instantaneous coupling. The barrel is filled in 30 seconds. It was possible with this arrangement to sink in Pennant sandstone, with 5000 galls. per hour, at the rate of 5–5½ yds. per week, or with 7000 galls. rather under 4 yds., the rock being very hard and compact. The highest rate of progress in the same ground with only 500 galls. per hour had previously been 6½ yds.*

KEEPING OUT WATER BY TUBBING.—Ordinary masonry is of little use for stopping back water, if the measures contain large quantities, and it is desired that this should not have to be continually dealt with. As a rule, it happens that water-bearing beds are usually succeeded by others of an impervious nature, so that if there can be introduced at such point some water-tight material, the water is prevented from coming into the pit. Such lining is called tubbing. The material employed may be either wood, cast-iron, or masonry; the former, however, is seldom employed at the present time. Its up-keep is great, it is scarcely ever water-tight, and its only recommendation is cheapness in first cost, where wood is plentiful.

Coffering.—Where the pressure is not excessive, a special setting of masonry, technically called "coffering," is largely employed. It is cheaper than cast-iron, and where properly put in is very successful. The following is a description of what is probably the largest application of this method, the shaft being 20 ft. diam. in the clear, the coffering extending about 55 yds. (from a depth of 105 yds. to 50 yds. below the surface).

After passing through the water-bearing beds, the shaft was sunk 20 yds. below the point where the last feeder was met, and a cast-iron curb put in, and supported on iron plugs. Upon this, about 26 yds. of 14 in. brickwork was built, and then the walling was carried up solid for 12 ft., until the water-bearing strata were met with. The object of doing this was to provide some substantial support for the coffering, and to prevent any risk of the masonry settling and cracking. It was decided to put in the coffering 2 ft. 3 in. thick. Some means have to be adopted to carry off the water running from the rocks, and to prevent it passing over the brickwork and washing the mortar joints away. To do this, what are called "plug boxes" were bedded on the solid work. Six of these were placed at equal intervals around the circumference, and were formed of wood, 12 in. square by 2 ft. 9 in. long, having a hole 3 in. diam. bored along their longer axis to within 2 in. of the back (*a*, Fig. 114), and then a vertical hole, *b*, bored from the top to meet the horizontal one. In this latter, vertical wooden pipes having horizontal openings were carried up behind the brickwork, and allowed the water to pass away through the openings in the plug-boxes. The holes in the water troughs were bored at vertical intervals of 3 in. As the brickwork and puddle reached each hole it was plugged up and the water conveyed away through the next higher one. The solid walling was then brought up level with the top of the plug-boxes and the coffering commenced.

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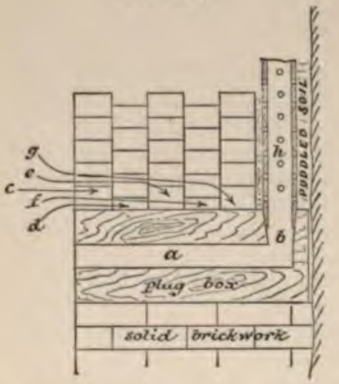
* So. Wales Inst. xvi. 119.

FIG. 114.



This consisted of five rings of brickwork, the special feature of this system being that the joints are broken both vertically and horizontally. Header courses are not employed, stretchers only being used. To commence with, the first ring, *c*, is of ordinary brick 3 in. thick, the second ring, *d*, for the *first* course is laid with bricks 1½ in. thick, the third and fifth rings, *e* and *g*, are similar to the first one, while the fourth ring, *f*, for the *first* course is also made with 1½ in. bricks; afterwards, ordinary bricks, 3 in. thick, are used in all the rings, so that the horizontal joints of the second and fourth courses throughout the work are the thickness of half a brick below the others. The method of laying the bricks is the usual one for the first, third, and fifth courses, and when these are in position, the spaces between are filled with thin liquid cement, and the second and fourth rows are laid by dropping the bricks into the mixture reposing in the gullet, these being what are called "floating courses."

After getting up about 12 or 18 in. the space between the back of the brickwork and the strata is filled in with good loamy soil, which should be free from pebbles and should be well and carefully rammed, no spaces being left. Instead of soil, well puddled clay is sometimes used, but experience is more in favour of the former. With clay, no matter how carefully the work is done, there is a tendency for "faces" to be formed between successive layers and lumps, through which water finds its way. The mortar used for laying the first, third, and fifth rings was a mixture of lime, cement, and ashes well ground in a mortar mill; for the intermediate rings, pure Portland cement was employed.

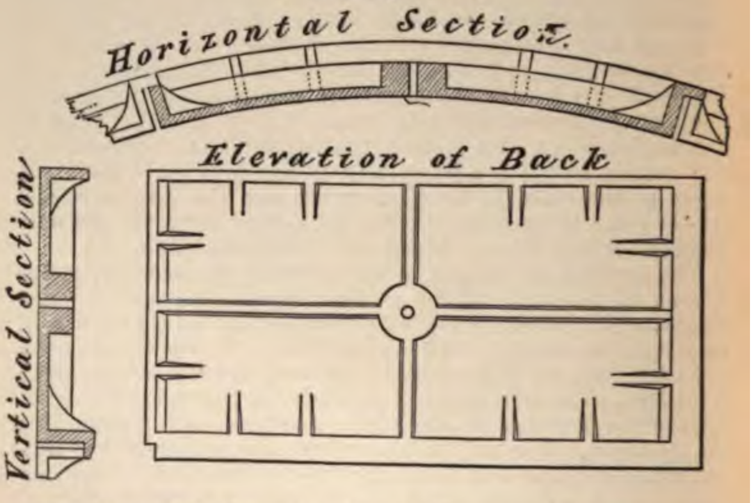
Iron Tubbing.—Where the pressure of the water is great, and long lengths have to be put in, masonry tubbing is not applicable; indeed every form has given way to that in which cast-iron is employed. At one time rings going completely round the circumference of the shaft were employed, but the difficulty of getting them into position, and their liability to break, together with the impossibility of repairing them, caused an early abandonment of this form, and the use of segments has now become general.

At first the flanges were placed towards the centre of the pit, and the attachment of one to the other was made by means of bolts, but in consequence of the lowering of the ground, and the effect of side pressure, it was found that bolts were not to be trusted, and that frequent ruptures took place. In England this method has given way to the system in which the flanges are placed away from the centre of the pit, it being found that the pressure of the sides and the wedging which is adopted, is sufficient to retain the segments in position, and to keep the joints watertight. The author was surprised to find on a visit (in 1891) to the Continent, that the old system of placing the flanges towards the inside of the shaft was still in use there. The engineers at the different collieries visited contended that no reliance could be placed on wooden wedging, as it is always decaying, and that although some little difficulty is encountered through movements of the ground, these are counterbalanced by the more perfect watertightness of the tubbing. In this method the flanges, both horizontal and vertical, are planed in a lathe, and two V grooves cut in them. A layer of sheet-lead is then interposed, and the two segments screwed tightly together by means of turned bolts, the pressure forcing the lead into the V grooves already alluded to.

The method of putting in the work is the same whatever system is adopted. After getting through the water-bearing strata, and reaching some impervious beds, a bed is first formed on which the wedging curb can be placed. This is dressed truly level with the aid of hammer and chisels, blasting being strictly forbidden, so as to obviate any possibility of fracturing the rock. This is the keystone of the whole operation, and requires the greatest care. Formerly wedging curbs were constructed of oak, but this has been abandoned in favour of cast iron. They are built up of segments which, in the case of upcast shafts and furnace ventilation, are sometimes of smaller diameter than the tubbing plates, the projecting portion being afterwards used as a foundation on which a lining of brickwork can be built. For an important undertaking they would be about 18 in. wide by 6 in. deep, and are cast hollow to lessen the weight. The segments of the curb are set in position on the bed prepared, and half-inch sheeting of soft deal placed in the joints in such a manner, in this and other cases, that the end of the grain of the wood is presented to the inner part of the shaft where wedging takes place. The important operation of wedging the curb is then commenced. All around the circumference, in the space between it and the sides of the shaft, is placed well-dried timber, free from knots, with the grain upwards. As many well-dried, finely-tapered, pitch-pine wedges as possible are then driven in, care being taken that this operation proceeds all round the shaft at the same time in order to distribute the pressure, and prevent any chance of the segments being displaced; props are also set from the sides over each joint to keep the curb from lifting. When no more timber wedges can be got in, steel chisels are employed, and, in the spaces they make, further wood is inserted. A second wedging curb is usually placed above the first, and sometimes a third one. The top one of these always has a rebate or ledge placed on it, against which the segments of the curb abut.

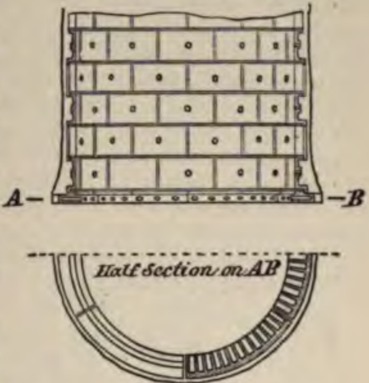
Tubbing plates (Fig. 115) are cast in segments of such a length that the circumference is divided into equal parts, their height varying from 18 to 36 in., according to the pressure to be resisted. Flanges, cross-ribs, and brackets are cast on the back to give strength, and a hole is provided in the middle of each to allow water to pass through while the operation of laying the plates is proceeding. The top and one of the side flanges are provided on the outside with a projecting ledge, which keeps the joint sheeting and adjoining segments in position.

FIG. 115.



When the wedging is finished, the first layer of tubbing plates will be laid on the curb, sheeting being placed between both horizontal and vertical joints, and a wedge tightly driven down between the back of the plates and the sides of the strata as a preventive against any of the segments moving. A second layer of segments is then laid on the first in a similar manner, and the process repeated until the top of the water-bearing strata is reached, the vertical joints being broken in each course, as in building masonry (Figs. 116 and 117). The spaces between the plates and the sides of the excavation are filled in with soil or concrete packing. A wedging curb will be placed on the top if it is found that the water rises above the level of the last line of plates. All the horizontal and vertical joints are then carefully wedged, as long as the grain of the wood between the joints can be opened with a chisel, commencing at the bottom and proceeding upwards, attacking each ring in order, and plugging up the hole through the centre of each segment at the same time. If this operation is carefully performed it will be found that the length tubbed will be quite dry.

FIGS. 116 AND 117.



In many instances much time and money is saved by not waiting until the bottom of the water-bearing beds is reached, but putting in wedging curbs at intermediate places and building tubbing up from one to the other, successive feeders of water met with being thus kept out of the shaft. Of course, for the success of this operation, it is necessary that the nature of the beds met with is such as affords foundation for the curbs, but although each wedging curb may not be water-tight during the time of sinking, yet when the pressure of the lower length of tubbing is brought up against it such leakage may be altogether or nearly stopped, and, although each foundation may be bad by itself, yet when they are brought to bear in support of each other, the water may be stopped back. In the Seaham winning* ten successive lengths of tubbing were thus put in, and, although the total quantity of water which the engineers had to contend with at different periods of the operation was 6240 galls., yet never more than 540 galls. per minute was actually in the pit bottom, this being the maximum amount, the average quantity being 136 galls. The total amount of water tubbed back was 4880 galls. per minute, which would have been the quantity required to have been raised or pumped to the surface, if intermediate wedging curbs had not been inserted. After reaching an excellent foundation in the coal measures, three main wedging curbs were put in as the base of the iron tubbing, and the sinking through the coal measures commenced without a drop of water in the bottom.

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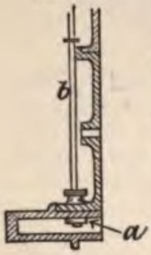
* N E. I. v. 117.

Messrs. J. J. Atkinson and W. Coulson* were the first to point out the curious accidents which happen to tubbing fixed between an upper and lower wedging curb through the confinement of water and *gas*. It has never yet been satisfactorily explained, how air and gas confined behind tubbing can have a greater pressure than that due to the hydrostatic head, but it is a fact that such is so, and unless some escape is provided, no matter how thick the tubbing is, the inevitable result will be that it becomes cracked or displaced from its seating. To prevent such occurrences, either the water behind each lift is connected with the water behind the other lifts, by means of small pipes, and thus, in effect, rendering the whole of the tubbing open-topped through the medium of the uppermost lift, or a pipe is carried up from behind the tubbing to the height necessary to balance the pressure of water. As this takes up a large quantity of pipes, a short length is sometimes inserted through the tubbing near the top of the lift, and only extended a small distance up the shaft, but a loaded valve is provided at the top, where all the pressure of the water is. This valve discharges the air and prevents the pressure getting higher than is due to the water alone.

FIG. 118.



The more general practice is to place a valve *a*, Fig. 118, in the wedging curb, and to carry a length of pipes *b* behind the tubbing to the next wedging curb. After the tubbing has been wedged and plugged, the water rises and drives out all the air. When water has been running through the pipe for some hours the valve *a* is closed.

Strength of Tubbing.—The thickness of cast-iron tubbing varies directly with the pressure it has to support and the diameter of the shaft. As the pressure also varies as the depth, if the diameter and the depth are both doubled, the thickness of the tubbing will have to be increased four times. Mr. J. J. Atkinson† gives a complete reasoning for the following formula, from which the thickness at any depth can be found:

$$t = \frac{6d}{\frac{m}{p} - 1}$$

where t equals thickness in inches, d equals the diam. in ft., p equals the pressure in tons per sq. inch due to depth, m equals the working load or resistance to crushing of the material employed. Remembering that a cub. ft. of water weighs 62.5 lbs., 12 cub. in. will weigh 0.434 lbs., so that for every foot of depth a pressure of 0.434 lbs. per sq. in. is exerted. To obtain, therefore, the pressure per sq. inch due to any head of water, the depth from the surface in feet is multiplied by 0.434. The resistance of cast-iron to crushing (average of various qualities) is about 90,000 lbs. per sq. in., but to be on the safe side, $\frac{1}{6}$th of this amount (15,000 lbs.) is taken as the working load, and should be substituted as the value of m in the formula given above. To the thickness so found, $\frac{1}{8}$ inch should be added to allow for corrosion of metal and wear and tear.

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* N. E. I. xi. 9.

† *Ibid.* ix. 175.

In shafts of large diameters the thickness of the upper segments should never be less than $\frac{5}{8}$ inch, or they are liable to be fractured by blows. In the above formula notice is not taken of the strength imparted by flanges and ribs, which will give additional security. Theoretically each segment should be different in thickness to the others, but as this would involve considerable expense in casting, the thickness is varied about every 8 or 10 yards.

Corrosion.—Certain substances contained in solution in water have a very injurious effect on iron, saline matters and chlorides being especially destructive. No satisfactory means have yet been devised for stopping such action, the best preventive, probably, being a coating of a hard varnish applied before the tubbing is seated. The front of the segments in upcast pits, where furnace ventilation is employed, is also attacked by the gases generated by the combustion of the coal. Sulphurous acid is produced, and mixing with water forms sulphuric acid, which rapidly eats away the iron to such an extent that in a few years its nature is completely destroyed, and it gets so soft that it can be cut with a knife. The best and generally used preservative is a lining of fire-brick, a seating for it being made by fixing one of the wedging curbs so that it projects from 3 to 6 inches into the shaft. The great objection to this procedure is, that by covering up the face of the tubbing, the detection of leaks is made difficult, but of the two evils the lesser is chosen.

Cost of Tubbing.—Mr. G. C. Greenwell* gives the following statement of the actual cost of putting in metal tubbing in a shaft 14 ft. 9 in. diameter:

Cost of wedging curb:—

	£	s.	d.
Dressing and preparing bed for curb, and laying same ready for wedging	34	9	0
Wedging (stone very hard)	10	4	11
Wedges (5435 used) and sheeting (material and manufacture)	5	3	2
Wedging curb (10 segments, each 7 cwt. 1 qr. 17 lbs. = 74 cwt. 2 lbs., @ 6/9 per cwt.)	24	19	7
	£74	16	8

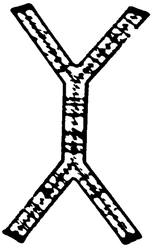
Mine Engineering, pp. 166–169.

of which has a bottom flange turned outwards and an upper flange turned inwards. These two are strung together by iron tie-rods *c*, and the space between them completely filled with moss, so that when the upper one slides down, this moss is compressed. Other segments are connected above these two rings, all of which have the flanges pointing inwards. The tubbing consists of cylindrical rings, about 4 ft. 6 in. high, cast in an entire piece. There are no vertical joints. A strengthening rib is cast inside each ring, and the top and bottom flanges are turned in a lathe, and bolt-holes bored in them. Before being used, each ring is tested by hydraulic pressure, in a specially constructed box, with from two to five times the pressure it has to support. These rings are put together at the surface with $\frac{1}{8}$th of an inch of sheet lead between the joints, and the whole structure lowered bit by bit, by screws and strong iron rods.

The chief point upon which successful lowering depends, is the means adopted to balance the enormous weight of the long length of tubbing. Near the bottom a diaphragm (*d*, Fig. 121) is fastened to the flange of one of the segments, and in the centre of this is a tube. When lowering is being carried on, the weight of the tubbing forces the water up the central aperture; the amount displaced by the diaphragm and the resistance it meets with during its passage through the water are so great, that a large portion of the weight of the tubbing is supported; indeed, in some instances, it is more than counterbalanced, and where such happens, water is introduced at the top of the diaphragm, to be pumped out again if necessary. This regulation is operated so successfully, that in one case where the entire weight of the tubbing was 800 tons, it was so counterbalanced that not more than 40 tons was ever on the lowering rods at one time.

Lippmann's Method.—To the foregoing method several objections may be taken. It has been found that nearly as much time is taken to enlarge the small shaft as to bore it, and attempts were therefore made to carry out the whole operation at the same time. With a straight chisel turned round a centre, blows are struck more closely near the centre of the shaft than at the circumference, and considerable labour is wasted. Messrs. Lippmann have got over this difficulty by making a drilling tool in the shape of a double Y (Fig. 122), in which two teeth are placed in that portion cutting round the circumference of the shaft, and only one towards the middle; more blows are thus given at the periphery than at the centre. Another improvement is that the engine is not connected directly to the boring lever, but motion is communicated by means of an endless chain and eccentric, which prevents all shock. The débris is extracted by an iron box,

FIG. 122.



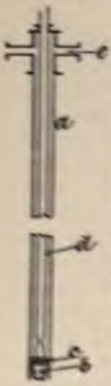
divided into three compartments, each of which has nine holes, closed by valves opening outwards. This box is lowered to the pit bottom, and alternately raised and dropped for about 15 minutes, being at the time gradually turned round. The sludger has usually to be filled twice before recommencing to bore. For securing the sides, similar tubbing to that of the Kind-Chaudron method is adopted.

SINKING THROUGH QUICKSANDS. — Triger's Method.—In this system, sheet iron cylinders, divided into three air-tight compartments, are sunk into the ground, and compressed air forced into the lower one. The workmen are thus placed in a sort of diving-bell, and if the pressure of air is greater than that of the water in the sand, the latter is forced back, and prevented from entering the lower compartment. The rubbish excavated is removed in a small kibble. Trap-doors allow communication from one chamber to the other, the joints of these being made carefully air-tight. The doors of the second and third chambers are never allowed to be opened at the same time, so that little loss of compressed air takes place. Sinking proceeds until solid ground is reached. The depth which can be attained by this method is limited, for as the pressure of water outside the cylinder increases with the depth, a higher pressure of air has to be used in the lower compartment to stop the influx of water, and a point is soon reached above which the men cannot work. At Aix-la-Chapelle, 121 ft. of quicksand was passed through by this method, the greatest pressure of the air employed being 2.8 atmospheres.

Poetsch's Method.—The most recent improvement for sinking through water-bearing strata, is that introduced by Mr. Poetsch, which consists in freezing the running ground, and transforming it into a solid mass of ice, through which sinking proceeds by ordinary methods, just as if the ground was of a tenacious and solid character. A well-known principle is that, when any liquid is rapidly converted into vapour, it absorbs a considerable quantity of heat, and that the absorption is more rapid the more volatile the liquid. In the machine employed for producing the freezing mixture, liquid ammonia is placed in connection with the receiver of an air-pump, and rapid exhaustion set up. The ammonia at once commences to boil, and the vapour produced is absorbed by suitable means, with the result that a still more rapid evaporation is produced, which communicates intense cold to the mixture employed for the freezing operation. The liquid used for this purpose is a solution of chloride of calcium, adopted because it does not freeze until the temperature reaches $-34°$ C.

The actual procedure is as follows:—A series of bore-holes are sunk through the water-bearing strata until the solid measures are reached, and are lined with tubes (*a*, Fig. 123) as they go down. After penetrating through the quicksand, the lower ends of these tubes are made water-tight by means of lead stoppers *b*, and several layers of cement *c* are poured into the interior. The greatest care is exercised in getting the joints of the outside pipe water-tight, as if they are not, the solution of chloride of calcium escapes into the ground, and renders freezing very difficult. Into the centre of each of these larger pipes a smaller one *d*, of about one-third the diameter is introduced, having its lower end open. These latter pipes are provided with stop-cocks, and joined to a central distributing pipe, suspended above the top of the shaft. The freezing mixture, prepared as above, is then forced by a pump down the small tube, and on reaching the bottom circulates in the annular space between the two pipes, rises to the surface of the ground, and is collected in another series of pipes *e*, from whence it is again returned to the freezing machine, and used over again. By this means the ground between each pipe within the shaft itself, and also the ground outside the limit of the shaft, is frozen hard enough to give solidity. The most intense cold is at the bottom of the pipes, and as a result small cones of frozen ground, with their bases downwards, are first formed, the dimensions of which increase progressively.

FIG. 123.



The method of sinking after the ground is frozen, is to excavate a space with the aid of picks and wedges, blasting being expressly forbidden, and then to secure the sides by means of ordinary curbs, and laggings. Second and further lengths will be sunk, and timbered, in a similar manner, until the quicksand is passed through and solid ground reached, when a wedging curb will be put in, and cast-iron tubbing brought upwards.

At Emilia Pit, Germany,* the apparatus was charged with 950 quarts of solution of ammonia, the daily consumption of which was about 3 qrts. Freezing occupied 53 days, when sinking was commenced and done without any difficulty, at the rate of about 2 ft. per day. Sinkers were paid 55*s.* per running yard. The circulating tubes were removed very easily, the solution of chloride of calcium being passed through them *heated*, instead of cooled. Total cost of plant was £3000; expense of erection, £960. Total cost for shaft, completed and walled, allowing 25 per cent. of first cost of plant, for depreciation and expenses of erection and removal, was about £26 per running foot.

Deepening Pits already Sunk.—The common way of doing this, without stopping the pits drawing coal, is with the aid of a tail-rope fastened below the cages. If any depth is to be carried out, the rope employed will be made in two lengths with a view of saving time. The preparation is rather a simple one. First of all, means are provided at the inset level, for receiving the débris out of the sinking kibbles. Then an ordinary rope is provided with a capping at each end, and the upper one passed through the bottom of the cage, and made fast by driving an iron pin through the eye of the capping, and usually further secured by glands to the bottom of the cage. The kibble is attached to the other end of the tail-rope, and when the cage is raised by the winding engine at the surface, the kibble is lifted also. The method of procedure is to fill a kibble at the bottom where sinking is going on, lift it to the inset, empty the contents into tubs standing there, and then lower down again. Sufficient tubs are provided to contain all the dirt produced in the night-time, and the tail-rope is then taken off the cage (an operation done in five minutes), the cage lowered to the inset level, and the débris wound to the surface.

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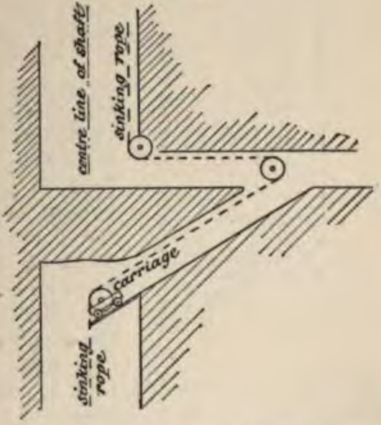
* For. Abs. N. E. I. xxxiv. 72.

The above system can only be applied when the pit is not winding coal. In many cases this difficulty is surmounted by commencing at the inset level, a short distance away from the shaft, and sinking an inclined pit until its axis meets that of the drawing shaft, when it is continued vertically downwards. At St. Adolphe Pit, Haine St. Pierre Colliery,* with such procedure, the shaft was deepened from 984 to 1246 ft. without stopping winding. The débris was drawn by an engine at the surface, a rope from this passing down the side of the winding pit, and then deflected by pulleys along the line of the incline, finally passing into the vertical position required for sinking, by being conducted over a pulley supported on a carriage, the rope passing through a hole in this (Fig. 124). When the kibble is at the bottom of the sinking, the carriage is at its lowest point, and the rope hangs vertically in the pit, but as the kibble is lifted the carriage is pushed up the incline, the kibble hanging in a vertical direction until the inset level is reached, when it is removed, and an empty one put on. On the return journey the carriage follows the kibble as it is lowered, until it comes to the end of the guide. The rope then descends vertically downwards. A spring is placed just above the capping on the rope to prevent any shock when the kibble strikes the carriage.

FIG. 124.



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* For. Abs. N. E. I. xxxvii. 58.

At Alexandra Pit, Wigan, a shaft 19 ft. diam. was deepened from 260 to 772 yds. in two years by the following method, coal being wound all the time. One cage was taken out, and a balance weight, equal to a cage and four empty tubs, put in its place, this working down the side of the pit on two guides, the winding rope being diverted from its ordinary position by means of a pulley on the head-gear (Figs. 125 and 126). Three scaffolds were put in at the Pemberton 4 ft. inset, to prevent anything falling on the sinkers, and a hole left through for the passage of the kibble. A platform on wheels was provided on a level 6 ft. higher than that employed for caging the coal, which could be run over the hole left in the scaffolding. A small winding engine at the surface drew the sinking débris from the bottom of the shaft up to the level of this platform, which was pushed over the shaft, the kibble removed, and the dirt tipped into ordinary tubs standing at the level of the inset. These were then placed on the cage, and drawn to the surface. A capstan rope, worked by a special engine at the surface, passed down the *centre* of the shaft and formed a guide for the sinking kibble, during such times as bricking was not being proceeded with. When this rope was not in use it was kept in position at the bottom of the pit by a heavy circular elongated block of iron. Fig. 127 gives an enlarged view of the guide employed; *a* is the capping of the winding rope, to which is attached the detaching hook *b*. Below this comes the guide *c*, and weight *d*, the latter being of cast iron with a hole bored out to receive the vertical bar *e*, which fits into *d* loosely, so as to be readily withdrawn for examination. Above the weight a horizontal bar *c* projects, clasping the bar *e* above the weight, and projecting to the capstan rope on which it runs freely with plenty of "play." Below the weight comes the kibble and bridle-chains. The capstan rope *g* is placed absolutely central in the pit. When about to fire shots the men were signalled away first,

FIGS. 125 AND 126.

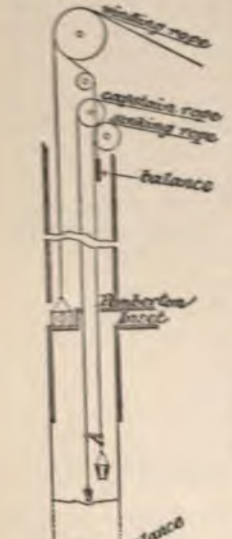
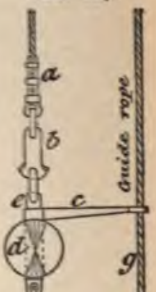


FIG. 127.



and directly they had gone, the capstan rope and weight attached was raised a few yards so as to be out of the way of the débris.

The bricking scaffold was made of timber, and suspended from bridle chains, and consisted of three parts, a centre one and two side pieces working on hinges. During bricking operations the winding rope was drawn up clear, the weight on the capstan rope taken off, and the latter connected to the bridle-chains of the scaffold, which, when not in use, was suspended in the shaft from cross baulks placed there on purpose.

For short distances, shafts are sometimes sunk upwards. A dividing brattice is usually placed across the shaft, and the débris allowed to accumulate over one-half of its area, this forming a sort of natural platform on which the men stand to work. For the purpose of ventilation, wooden boxes, or troughs, are built in the débris.

Widening Shafts.—This is a very awkward and costly operation, if winding is to be carried on at the same time. In such cases, it is usual to place a series of byatts, or buntons, below each other, in such a position that the cage misses them. At night-time these buntons are covered over with planks, and scaffolds formed, on which the men work, and take out the ground.

If the shaft is not required for winding purposes, the best procedure is to fill it up to the surface with some loose non-coherent material, which is removed again as the old lining and sides are taken out to the required size. This saves all the labour and time of changing scaffolds. In a deep shaft, portions only of its length would be filled up at a time.

Cost of Sinking.—The cost depends on the hardness and inclination of the strata, and especially on the quantity of water. If the beds are highly inclined, the cost is greater, as the rocks do not blow well. The general rule is to obtain tenders for sinking and walling the whole depth, and to deal with a certain quantity of water. If this quantity is exceeded, either allowances are given or the contract broken. Such contracts act very well, if the nature of the ground is well known, and no difficulties are encountered, but master-sinkers, as a rule, are persons of small capital. So long, therefore, as they are making money, everything proceeds smoothly, the manager is relieved of anxiety, his only care being to see that the work is carried out properly and with safety. But if the work is proceeding at a loss, the contractor's means are soon exhausted; although sureties are generally bound by agreement, yet concessions have to be made. In view of this, the system of carrying on by men at day wages is gaining favour, superintendence being given by competent chargemen, who, in addition to a stipulated wage, receive a bonus for every yard done during the week, in excess of a stated distance.

At Ramrod Hall Pit, Staffordshire, through the different varieties of the rocks of the coal measures, the cost of sinking was 11.12 shillings per cub. yd., which sum included the labour of putting in the walling 9 inches thick and backing the same with soil, all wages above and below ground (except winding engineman and stokers), blacksmithing, powder, &c.; value of materials used for lining not included. Colliers' wages at this date were 10 per cent. above minimum of sliding scale. The amount of water was small, and could be dealt with by baling. An allowance of 25*s.* was made for each water ring put in.

At Sandwell Park Colliery, the contract price for sinking and walling the No. 3 shaft, 15 ft. diam. in the clear, was £8 12*s.* 6*d.* per running yard, equal to 6.82 shillings per cub. yard of excavation. The above price rose at the same percentage as colliers' wages, which at that time were 3*s.* 4*d.* per day, the minimum of the sliding scale. The contractors found all labour in pit, banksmen, tools, blasting agents, lights, &c., fixed all scaffolds, ventilating pipes, &c., and deposited the spoil at such places as required, up to 40 yards from pit top The company found engine power, enginemen, sinking kibbles, lining material, and sharpened all tools. No allowance was to be made for water until the quantity exceeded such as could be raised by tipping barrels. The total sum paid under this head for the entire sinking, amounted to £6 16*s.* 9*d.* For each water ring put in £2 was paid, and for each square curb £3 15*s.* The average rate of sinking and walling (working continually from Monday morning to Saturday night) was 8.04 yds. per week.

Messrs. Forster-Brown & Adams give detailed statements of the cost of sinking and walling two shafts, each 17 ft. diam., at Harris Navigation Colliery,* including all labour, coal at boilers, smith work, explosives, stores, &c. From their paper the following figures are extracted :—

Average cost per yd. for sinking 50 yds. in *shale* near bottom of shaft.

	Without Pumps.				With Pumps.			
	£	*s.*	*d.*		£	*s.*	*d.*	
Labour	9	8	2		10	2	4	
Materials (stores, explosives, &c.) .	2	11	4.8		3	0	4.9	
				£11 19 6.8				£13 2 8.9

Average cost per yd. of sinking 50 yds. in hard Pennant grit rock, with pumps.

	By Hand.				Using three Machine Drills.			
	£	*s.*	*d.*		£	*s.*	*d.*	
Labour	32	17	1		22	19	8	
Materials (stores, explosives, &c.) .	11	16	1.9		11	3	4	
				£44 13 2.9				£34 3 0

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* Inst. C.E. lxiv. 23.

Average cost per yd., in depth of 50 yds., of 18 inch walling with two iron curbs in such distance.

	£	s.	d.	
Labour (sinkers, masons, smiths, enginemen, &c.) .	4	7	11.4	
Stores (candles, oil and grease, sinkers' suits, &c.)	0	17	10.7	
Material (bricks, lime, and coal)	6	2	0	
				£11 7 10.1

Equal to £1 3s. 10d. per cub. yd. of masonry.

Where 82½ per cent. of the strata passed through was hard rock, and 17½ per cent. shale, the average depth sunk and walled per week, exclusive of stoppages, was, in a length of 69 yds., 2.19 yds.; while, where 38¾ per cent. was hard rock, and 61¼ shale, the speed averaged 4.08 yds. per week over a length of 421 yds. Towards the bottom, the ground only contained 6 per cent. of hard rock, and the speed of sinking and walling reached 6.77 yds. per week.

The following table shows the comparative cost of various modes of sinking through water bearing strata: *—

System.	Colliery.	Cost per foot of Sinking.		Total Depth of Sinking.	Strata passed through.	Time in Months.
		£	s.	Ft.		
Triger .	La Louvièrie	98	3	42	Quicksand	2
" .	Havré . . .	888	19	124	Running sand and water bearing chalk	48
Chaudron	L'Escarpelle.	20	17	331	Sand and chalk . . .	11
"	Saint-Waast .	37	8	321	Chalk, marl, and sand.	29
"	Saint-Barbe .	33	3	180	Clays, marls, and sand	18
"	Saint-Marie .	12	9	344	" " "	13
"	Rothhausen .	38	11	338	White marls	25
Poetsch .	Archibald. .	17	16	131	Quicksand	—
" .	Emilia . . .	25	16	140	Sands, &c.	8
"	Koenigs Wasterhausen	30	0	98	Sands with large boulders	6

Detailed statements of the cost of sinking several shafts by the Kind-Chaudron process will be found in the Colliery Guardian of Jan. 23, 1880, p. 129.

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* For Abs. N.E.I. xxxv. 33.

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FED. INST.: *Notes on the Sinking at Lens Collieries by the Poetsch System*, N. R. Griffith, ii. 441.

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BRIT. SOC. MIN. STUD.: *Details of Sinking Upwards*, H. Jepson, i. 134; *Sinking at Aldwarke Main Colliery*, A. Mirfin, i. 186 and 222; *Sinking through Quicksands, Marls, and Gravel Beds*, R. Clough, xiv. 106.

SO. WALES. INST.: *On the Tubbing of Shafts*, E. Hedley, iv. 104; *Personal Experiences in Tubbing Shafts*, Geo. Wilkinson, x. 191; *Excavating below Water Level by means of Compressed Air*, Wm. Galloway. x. 252; *An Account of the Sinking and Tubbing of a Pumping Shaft at Radstock Collieries*, J. McMurtrie, xi. 66; *Poetsch's Freezing System of Sinking through Quicksands*, R. de Soldenhof, xv. 143 and 349; *Sinking Appliances at Llanbradach*, Wm. Galloway, xvi. 107 and 268.

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N. STAFF. INST.: *Sinking through Quicksand at Podmore Hall Colliery*, W. R. Wilson, vii. 113.

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The Freezing Process as applied at Iron Mountain, Michigan, in Sinking a Shaft through Quicksand, D. E. Morgan, School of Mines Quarterly, New York, vol. xi. p. 237.

CHAPTER VI.

PRELIMINARY OPERATIONS.

Underground Roads.—Having reached the seam from which mineral is to be extracted, the first operation consists in driving a series of passages called levels or roads. Their direction is governed by the relative position of the shafts and the area to be won, by the system of working adopted, and by the inclination of the seam. Their size is governed by the dimensions of the tubs employed and by the proposed system of haulage, as, if a double line of rails has to be used, the dimensions of the roads will necessarily be larger than where only a single line is in operation. The direction is also influenced by the question of haulage, for if mechanical means are not employed, the gradients of the roads will have to be such that a horse can readily draw material along them, and as the dip of the mine and the position of the shafts are fixed points, the roads in this case will have to be driven in such direction that the necessary gradient is given.

Another point is the question of dealing with water. Wherever possible, the gradients should be such that all water gravitates towards the shaft. Perhaps, in all seams of moderate and regular inclinations, the best plan is to drive the main road practically along the strike of the seam, only deviating from that line to such an extent as will give a slight fall towards the shaft. Where seams have undulating gradients, roads carried along the strike necessarily vary in direction with each change in the dip. For any system of mechanical haulage, the best results are obtained where the roads are driven straight, so that when the dip varies we usually find that the straightness of roads is more looked to than any actual question as to whether they are following the strike of the seam or not, as it only requires a little more engine power to haul along the material.

Means of Keeping Direction.—Having decided upon the position of the roads, they are kept in the proper direction by very simple means. At the commencement two or three points are determined, and marked on the roof, with the aid of a compass or theodolite, and plumb-bobs suspended from them in such a position that the straight line made by these three shall be in the direction in which the level is to be driven. Three points are much to be preferred to two, as in case any movement takes place in any of them, it is usually found out, such not being the case where only two are adopted; as an additional precaution, it is better that these lines should not be attached to timber frames or settings, or the pressure of the ground is liable to move them out of position. To determine whether the road is proceeding in the proper direction, an observer stations himself behind the plumb-bob farthest from the face, and lights are held against the other two lines. Another workman is stationed at the face with a light, which is moved about until its position coincides with the line given by the three fixed suspended plumb-bobs.

In some instances the points are fixed in the axis or centre line of the excavation, while in others they are placed nearer to one side of the road, of course preserving the same line of direction. In the latter case, the point obtained on the working face will not be the middle of the road, but somewhere about a foot from the side. This latter arrangement is preferable, because if the road does get slightly out of line when the determining points are fixed in the middle, the straight line given by these points will pass down the road (Fig. 128), but if such points are only one foot from the side it would be impossible to get the line through (Fig. 129).

FIGS. 128 AND 129.

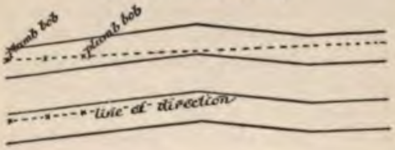
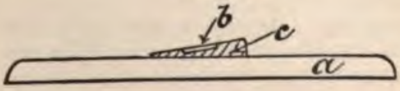


FIG. 130.



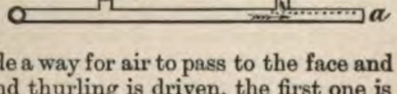
Means of Keeping Gradient.—For haulage planes uniform gradients are preferable, as the cost of cutting through small irregularities of the floor or roof, and indeed, dislocations caused by faults, is soon repaid by the ease and smoothness with which the plane is afterwards worked. In the case of large faults, modifications of the gradients have to be introduced, but even in such cases it is usual to make the inclination approach as near to the regular one as possible. The instruments employed for keeping the gradient uniform are also of a simple character. Often an ordinary T-bob (a wooden frame shaped like an inverted T) and plumb-line are used, the vertical piece being placed on such an inclination that it corresponds with that to be given to the floor. This is rather a clumsy instrument. A more convenient form is that of a straight edge (*a*, Fig. 130) about 6 ft. long, in the upper side of which a level, *b*, is bedded in a small secondary triangular block of wood *c*, the angle that this latter piece makes with the former being such that, when the bottom side of the straight edge is parallel with the line of inclination of the road, the level is truly horizontal.

Operation of Driving.—Having determined the direction and gradient, the work is, as a rule, carried out in the following manner:—The first operation consists in holing or undercutting the seam; that is to say, either the lower part of the coal is cut away with a pick, or, if a soft layer exists beneath the seam, undercutting is performed in it with the object of reducing waste, because holing the coal makes nothing but "small," which is comparatively worthless. The width of the undercutting is equal to the width of the road, but its depth depends entirely on the nature of the seam. Strong coals require deeper holing than tender ones. In performing undercutting, the miner lies on his side, and naturally removes more height at the face than at the back, because at the former place his arms and the helve of the pick have to be inserted, while at the immediate back only a space equal to the width of the tool is necessary. If the undercutting is deep, part of the man's body is also introduced, and consequently more of the coal has to be cut away. For this reason, except where the nature of the coal absolutely requires it, holing should not proceed any further under than a man can conveniently reach without inserting his body. The coal undergone is got down by cutting a vertical groove along one side, and then breaking down the remainder either by blasting or by wedging.

In some collieries gas exists in the coal under such pressures that it assists the workman in hewing the coal, and roads can best be driven by attacking the whole height of the seam at one time. If holing were resorted to, it would drain the gas, and render the operation of getting down the coal above, a more difficult and expensive one.

Ventilation.—Except under exceptional circumstances, one road is never driven alone, two parallel ones (*a* and *b*, Fig. 131) being carried forward at the same time, these being connected at intervals by other roads, called "thurlings," or cross cuts (*c*, *c'*), the object of which is to provide a way for air to pass to the face and ventilate it. When the second thurling is driven, the first one is blocked up by building a wall in it. Such obstruction is called a "stopping," its object being to force the air further inbye, and prevent it going back to the shaft until it has ventilated the workings. It is obvious, however, that the current of air will naturally pass through the last thurling, and when the road goes on further, the face will remain unventilated, unless some means

FIG. 131.



are adopted for carrying air to it. This is done by one of two methods: either by carrying bratticing, or by iron, canvas or wooden pipes called air troughs or "trows."

Bratticing is generally fixed by putting props along the line of roading, but instead of using ordinary short lids to such props, a long strip of wood about 3 in. broad is employed, and firmly secured against the roof by driving the prop beneath it. The brattice cloth is attached to these laths by nails, and temporarily divides the roadway into two, as shown by dotted lines in Fig. 131. The pure air passes up one side and down the other, as indicated by the arrows.

This system is largely employed, and is unsurpassed where the roof is regular, as the laths rest evenly against it, and form an air-tight joint. With irregular roofs bratticing is impracticable, and air troughs have to be used. These consist of sheet-iron pipes, with a socket and spigot end. A temporary stopping is built across the road, immediately before the last thurling, and one of these pipes put through it. As the heading proceeds, other pipes are added. The air passes through them, and back again along the road.

Supporting Roof.—In every mine the roof has to be supported, this usually being done by timber, owing to the facility with which it can be introduced into the workings, and replaced from time to time when necessary. The roof is tested by knocking on it with a pick, or other instrument, when, if insecure, a hollow sound is given out. It is not always possible to be sure by this test, as the occurrence of a number of small faults, or slips, makes the roof disjointed, and less tenacious than if none were present. Slips are unaccompanied by dislocation, and are very difficult to detect, even by careful observation. Where a seam is known to contain them, minute examination must be resorted to, as a place might look safe on inspection, and immediately afterwards come in.

It does not appear that the depth of the mine has any effect on the strength of the roof. The order of working successive seams has an influence on the roof of the contiguous beds, owing to the release of gas; but from observations made by Mr. A. R. Sawyer* in North Staffordshire, no definite results can be fore-shadowed.

Two systems are in use for the operation of setting timber; in one it is performed by the workmen themselves, while in the other a special set of men are employed for the purpose. Both systems have advantages. In the former, the miner immediately detects any change in the ground, and can at once set the required support, without running any risk while waiting for a deputy to come; in the latter, deputies are continually going round (oftener than in the other system), and as they have been brought up to this kind of work, are very skilful. In Yorkshire, certain special men go round to set timber, and prepare the working places for the men, leaving a sufficient quantity of timber cut into proper lengths, the workmen having instructions, in case the roof becomes dangerous, to set any extra timber necessary, or to leave the place and send for the deputy. In Lancashire, most of the colliers set their own timber in the face (not in the roads), and the props are drawn by officials. The colliers are subjected to the orders of the officials, who, if sufficient timber is not set, order more to be put up.

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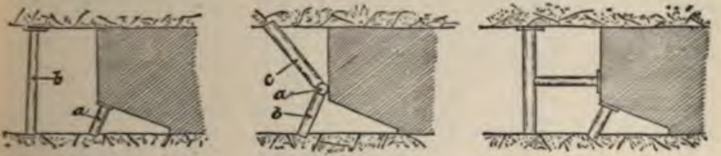
* *Accidents in Mines (Falls of Roof and Sides)*, p. 34.

The general experience seems to be that if a workman has to look after his own safety, and set his timber, he generally does it better than if it was entrusted to a deputy; while, on the other hand, an opinion is held that the miner, not being paid for setting timber, is apt to be negligent, to consider it time lost, and only put up props where absolutely necessary.

Timbering.—Of all the varieties of wood, fir and pine furnish the greatest proportion of that used in mining; larch may be considered the miner's timber *par excellence*. It can be obtained in good straight lengths, makes little waste in cutting, resists great pressure, and bends to a considerable amount before breaking, and its life is a long one, whether the place be wet or dry. For props, Norway fir is largely employed, and for such purposes is perhaps as good as larch, as it resists great pressure if such is applied along its length in the direction of the fibres, and is very straight, easily cut and fashioned; but it breaks rather easily when the pressure is applied transversely, and is therefore not trustworthy for bars. Oak for positions of reliability is universally employed, but is not used so much in roadways and workings, on account of its cost, and the fact that, excepting in large pieces, it grows very crooked, and is not easily shaped.

FIGS. 132, 133 AND 134.

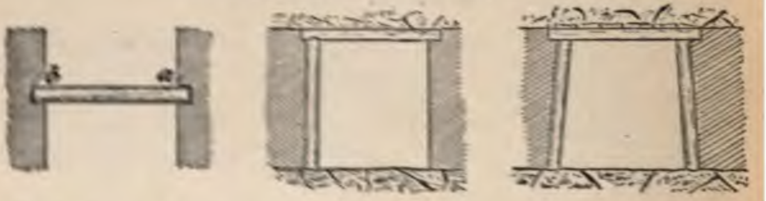


The simplest form of support employed is that known as the prop, or tree, which consists of a piece of timber fixed in a vertical position between the roof and the floor (*b*, Fig. 132). These are employed mainly in the working places, and almost invariably at the top of them is placed a small head-piece, for spreading the surface over which resistance takes place. This is called a "lid," and is generally a piece of wood 12 to 18 in. long and 3 to 4 in. thick, often made by splitting a piece of round timber through the middle. In the working place, two or three rows of these props are employed, those of two consecutive rows alternating with each other.

Small single props, called "sprags," are used for securing the coal during the process of holing (*a*, Fig. 132). An elaboration of this, employed where the coal is liable to break away from the face, is the special timbering to which the name of "cocker sprags" is applied, which consists of a longitudinal piece (*a*, Fig. 133) strutted against the face, and kept in position by the small sprag, *b*, going to the floor, and a second one, *c*, binding it from the roof. In other instances, a similar result is obtained by driving in a horizontal strut between the nearest row of props and the face (Fig. 134).

Where the roof is filled with faces which cross and recross each other, dividing it into a series of blocks, vertical props are not sufficient support, as they only keep up that part over or near the lid. In such cases, transverse pieces of timber, called "bars" or "struts," are employed. If the sides are firm, these bars may be supported on them by cutting a recess (*a*, Fig. 135) on one side of the road, and a groove, *b*, on the other, then inserting one end of the bar into *a*, and driving it tightly into the position shown. If one side of the road and the roof require support, often one bar and one prop are employed (Fig. 136). For the purpose of distributing the pressure, and increasing the surface of resistance, the timber is lined with boards, or laggings, placed longitudinally. If the roof only, requires support, laggings will be laid across from one transverse bar to the other; but if the sides are also bad, laggings will be placed all round the setting.

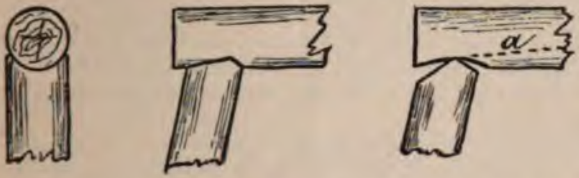
FIGS. 135, 136 AND 137.



For main roads and other positions, where the nature of the ground requires it, entire sets of timber are employed, these consisting of two upright props, and one bar on the top of them (Fig. 137), with laggings around. The chief point to be observed here is that no hollow spaces should be left between the laggings and the roof. If any exist, they must be filled up; if not, should the roof break away, it descends on the timber with a blow like that of a hammer, and often displaces it from position.

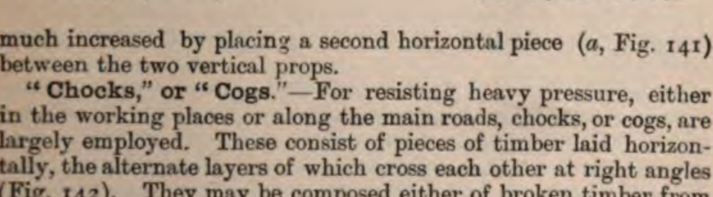
Joints.—The several pieces constituting a set are held together by different forms of "notching," each of which resists pressure coming from a certain direction. Where it is entirely from the roof, the common practice is to simply flatten the bar slightly at the point where it rests on the tree, and the weight soon tightens the pieces together. With a view of obtaining a larger bearing on the props, they are sometimes hollowed out at the top end (Fig. 138), the bar resting in the space so formed. It is, however, very difficult to shape this groove, so that an equable bearing is obtained, and if this is not done, the prop soon splits. To resist side pressure as well as pressure from above, the joint shown in Fig. 139 is largely employed. It is of the greatest importance that this should be nicely made, and that the end of the prop should fit evenly against the shaped portion of the bar. The great mistake is to shape the piece as shown in Fig. 140. If this be done the bar soon splits along the dotted line *a*.

FIGS. 138, 139 AND 140.



Where the side pressure is great, the power of resistance is much increased by placing a second horizontal piece (*a*, Fig. 141) between the two vertical props.

FIGS. 141 AND 142.

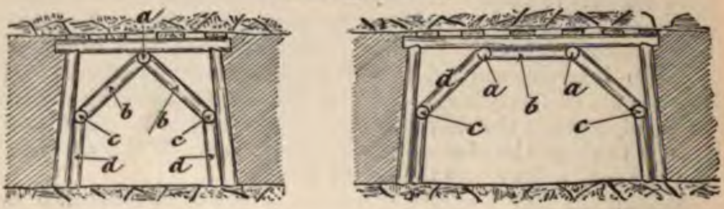


"Chocks," or "Cogs."—For resisting heavy pressure, either in the working places or along the main roads, chocks, or cogs, are largely employed. These consist of pieces of timber laid horizontally, the alternate layers of which cross each other at right angles (Fig. 142). They may be composed either of broken timber from the workings, or refuse material, such as old railway sleepers, waggons, or wreckages. If applied in the face, these chocks are built on a small heap of loose material, which allows them to be easily removed. If required to stand for any length of time, the space in the interior is filled in with loose dirt. Their size is an exceedingly variable one; perhaps the largest are employed in South Staffordshire, where they run from 9 to 12 ft. square, and 10 ft. high. They are capable of resisting enormous weights, as the more pressure applied the more they resist.

Double Timbering.—On the Continent, a system of double timbering is used to resist heavy pressure. The weakest part of a bar being its centre, it is strengthened there by a longitudinal piece (*a*, Fig. 143) kept in position by two struts, *b*, *b*, which rest on two other horizontal pieces of timber, *c*, *c*, these latter being finally fixed by two short sprags, *d*, *d*, resting on the floor. In such manner not only is the top bar strengthened, but the two side props as well.

So much of the useful space is taken out by the two angle struts (*b*, *b*, Fig. 143), that this style of timbering could not be employed if the road were a wide one containing a double way. The various parts are therefore arranged in a somewhat different manner. Two longitudinal timbers are placed beneath the bar, in such position that the distance between the props is divided into equal spaces. A transverse strut (*b*, Fig. 144) is put between the two pieces *a*, *a*, and the latter are kept in position by a series of cross-struts, &c., *c*, *d*, as before, as will be readily seen from the sketch.

FIGS. 143 AND 144.

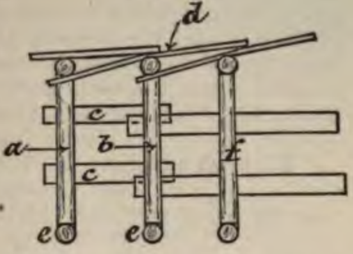


In fixing this interior frame, all the longitudinal pieces are first placed in position, and held there by a wire lashing, until the uprights and cross-struts are firmly wedged in their proper positions.

Driving through Loose Ground.—In driving through watery and loose ground, special timbering has to be adopted, and put in with a view of removing as little material as possible. The general name of "spilling" is applied to such operations. First of all, the frames (*a* and *b*, Fig. 145) will be fixed in position, and probably a sole piece, *e*, will be added, as well as the two uprights and the cap; then laggings or planks, *c*, *c*, are driven forward behind *b*, these being inclined slightly outwards, at an angle of about 15°

the pressure of the sides gradually bringing them close up against the sets. Other laggings are driven forward, inclined as shown at *d*, and a small quantity of ground excavated in front of *b*, until room is obtained for another set, shown *in position* at *f*. When this has been inserted, laggings will be driven, inclined outwards as before, for a similar length, and the process repeated until the ground is passed through.

FIG. 145.

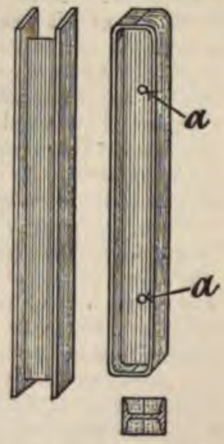


If the material is very loose, these laggings will have to be driven near together, and the joints between them made as close as possible, and occasionally, in some cases, the ground at the back of the road will have to be supported by planks, strutted against the first set.

The objection to this system is, that in spite of every care, a quantity of material oozes through the joints in very loose ground, leaving large empty spaces behind. To prevent this, the system on the Continent is to fill the face and the floor with a series of conical wedges, driving these forward, and so making progress. The sides and the roof are supported by laggings and sets, the former driven in, in the same manner as in spilling.

Iron and Steel Supports.—So far as props are concerned, no great success has yet been obtained, although in some instances they are largely used. The first cost of either iron or steel is always so much larger than that of wood, that if metal props are employed it is absolutely essential that none should be lost. If they are, the economy resulting from the decreased breakage is more than counterbalanced.

FIGS. 146 AND 147.

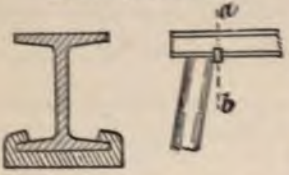


Cast-iron props have been tried, but have not met with much favour. They are somewhat easily broken, very heavy, and consequently dear.

Ordinary steel girders of the H form, if used as props, present a sharp and uneven surface to the roof, or floor, or to timber lids. Firth's arrangement removes this difficulty. A piece is cut out of the web at each end (Fig. 146), and a flat top and bottom formed, by turning over the top and bottom flanges until they meet (Fig. 147). In addition, holes, *a*, *a*, are punched in the web about a foot from each end, into which a hook may be inserted for the withdrawal of the prop.

The greatest application of steel girders in English mines is to replace the timber bars used on ordinary sets, retaining, however, the two vertical wooden props. It is obvious that, as the lower flange of the girder is smooth, and cannot be notched like a timber bar, if there is any side pressure, means have to be adopted to keep the props in their correct position, and prevent them from being pushed inwards. This is done in a very simple manner. About 4 to 6 in. from each end an ordinary chair is fixed on by the blacksmith, this consisting of a short piece of bar iron about 1 in. by ¾ in., crossing the bottom flange, and, turned round at each end, gripping the upper side. The enlarged sketch (Fig. 148) is a transverse section on line *a b*, Fig. 149. Any common scrap iron can be used for this purpose. The chairs are placed in position before the bar goes down the pit, and the labour cost for each girder for such adddition is 3*d*.

FIGS. 148 AND 149.

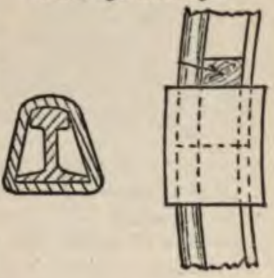


The author has had considerable experience of the utility of these steel supports. For bars up to 7 ft. long a section measuring 5 in. by 4 in. by ½ in., weighing 66 lbs. per yd., is employed, these costing 9.28*s*. They replaced oak bars, measuring 6½ in. quarter-girth, costing 2.66*s*. The price of steel was, therefore, 3.49 times that of wood. As an experiment, lengths of roading were timbered alternately with wood and steel (bars only, timber being used as props), but before any definite results could be observed, the district fired, was dammed off and abandoned. After a lapse of nine months the roads were reopened, and it was then found that the steel bars had scarcely suffered at all, only a few being displaced through their timber supports breaking. Owing to the fallen roof at places where timber bars had been set, over £100 in wages was spent in repairs, which would have been unnecessary had steel bars been employed throughout, and, in addition, the first cost of the timber was entirely lost. On a main haulage road, 12 ft. girders, of a section 6 in. by 4½ in. by ½ in., weighing 78 lbs. to the yd., and costing 20.95*s*. each, have been employed, replacing timber bars 9 in. quarter girth, costing 9*s*. each. The first cost of steel was here 2.33 times that of wood. The date of fixing each girder was noted, and numerous instances could be given of their lasting out from three to four sets of timber before removal. Two especially may be instanced; they were fixed at a junction, where the pressure was very heavy, and actually stood for 13 weeks before removal, while the longest time an oak bar lasted in the same place was a fortnight; many failed in a week, and it was quite useless putting in Norway timber, as it broke in two days.

If the steel bars were worthless on removal, the actual cost in the above instances would be less than timber, but all that has to be done is to take them out and straighten them, and then they are practically new. Their advantages are not so apparent where timber lasts a long while, but with heavy pressures, and in return air-ways, they are far superior. They must be set very carefully, with an equal level bearing, both on props and to roof; if not, they turn over and present their weakest side to the pressure. When they take a permanent bending set, the best thing to do is to either turn them over, or, if the bending is large, remove and straighten. With these precautions, the author has never had one break yet.

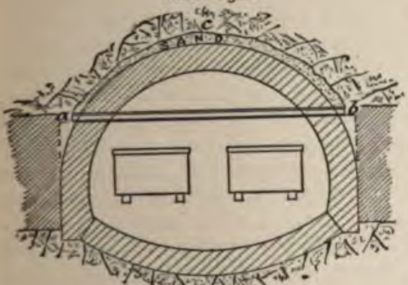
On the Continent, complete frames of steel are largely used. In some cases they are composed of two pieces, the top portion bent into the shape of an arch ⌒, and connected at the summit by fish-plates and bolts, the lower end resting on an iron shoe fitted to a wooden baulk, timber lags being driven behind the frames against the sides of the excavation. Elliptical shaped sets are also employed, but the common form is composed of two pieces of circular shape Ↄ. Instead, however, of making the joints with fish-plates, the frames are connected together by a sliding iron collar, which is secured in its place by driving between it and the frame two pieces of wood like rail keys. Figs. 150 and 151 show the application of such a joint at Firminy, where old pit rails are used.

FIGS. 150 AND 151.



At Lens timber lags have been done away with, and small strips of channel steel, about 2 in. by $\frac{5}{8}$ in., used in their place. Another advantage of steel is that it does not occupy so much space either as timber or masonry, and either a greater effective area of roadway for the same amount of excavation is secured, or the cost of driving the road is reduced, because less excavation is required to get the same effective area.

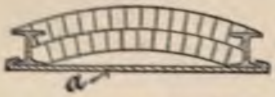
FIG. 152.



For permanent situations, where girders are placed on masonry side walls, considerable economy results. The worst feature about an arch is the large amount of space which is lost through the semicircular form at the top. Taking an ordinary roadway (Fig. 152), occupied by two tubs, an arch has to be so made that the curve of its upper portion allows the tubs to pass through without catching, and as a result, a high space exists in the centre, which not only costs a lot of money to excavate, but serves no useful purpose. If a girder, *a b*, be placed on the top of the walls, the excavation of the area, *a b c*, which contains 4.28 cub. yds., becomes unnecessary, and, in addition, the cost of the brickwork will be saved. In the illustration under notice this will amount to 2.08 cub. yds. per lineal yd., which will cost for labour, material, and mortar quite 29.32*s*. Against this has to be put the price of the girder, amounting to 20.95*s*. One of these will be required for each lineal yard. The girder and side walls, therefore, effect a saving in first cost of 8.37*s*. per yd. run in material, to which has to be added the reduced cost of the excavation, in this case at least 14.98*s*.

Side walls and girders are not so capable of resisting side pressure as an arch, but this difficulty can be overcome by turning small brickwork arches in between each girder (Fig. 153) in the same way as is done with fireproof floors of buildings. There is a certain amount of spring in steel girders, and, when weight comes on to these small arches, there is a risk that the girders will bulge in the middle, and allow the arch to flatten. To prevent this happening, tie-rods (*a*, Fig. 153) are placed across from girder to girder.

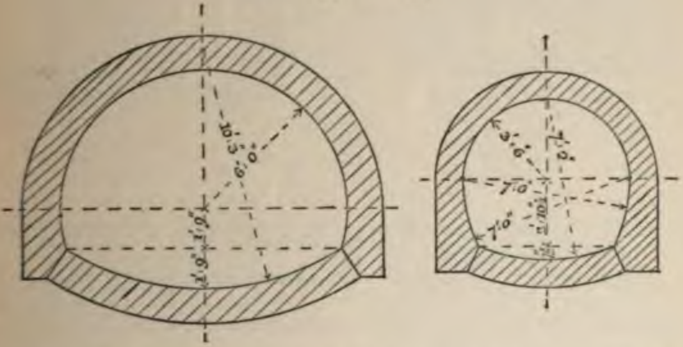
FIG. 153.



Masonry.—For all permanent situations, securing the sides with masonry still finds greatest favour. It is, perhaps, more expensive to put in for reasons already stated—viz., the greater excavation required, both for the masonry itself, and to obtain the same effective area, but when required to stand for many years it cannot be surpassed. It is, however, necessary to make the lining continuous all round the road. The practice of building arches without an invert is not to be recommended; if an arch is worth putting in at all, it should be put in well, and, in addition, some soft packing material, such as sand, must be introduced between the lining and the strata. No vacant places should be left behind the brickwork, and all timber used for the temporary support of the excavation, while the work is being put in, should be removed. The introduction of a soft material between the brickwork and the strata not only distributes the pressure over a considerable area of brickwork and prevents local weight, but, as it gradually gets compressed, acts as a resisting medium itself. This packing should not be too much nor again too little; from 6 to 12 in. gives the best results. To show how important it is, the result of an experiment, made by the author in 1888, may be cited. Two successive lengths of 7 ft. arch were built, one 18 in. thick, packed with a foot of sand, and the other, not less than 18 in., but made solid. The latter was crushed to pieces and had to be taken out in a year; the former is still in and does not show a crack.

The shapes of arches are many. The circular form is the strongest, but requires so much excavation that it is seldom employed. An ellipse is perhaps the next strongest, but this again requires a large space. The form generally adopted is a combination of the two. The side walls and top usually form part of one curve, struck with a radius equal to half the width of the road, while the invert, or bottom, is a portion of another circle having a larger radius. This ties the whole structure together, and prevents either the bottom lifting up or the sides heaving in. Two forms adopted by the author for a single and double way are

FIGS. 154 AND 155.



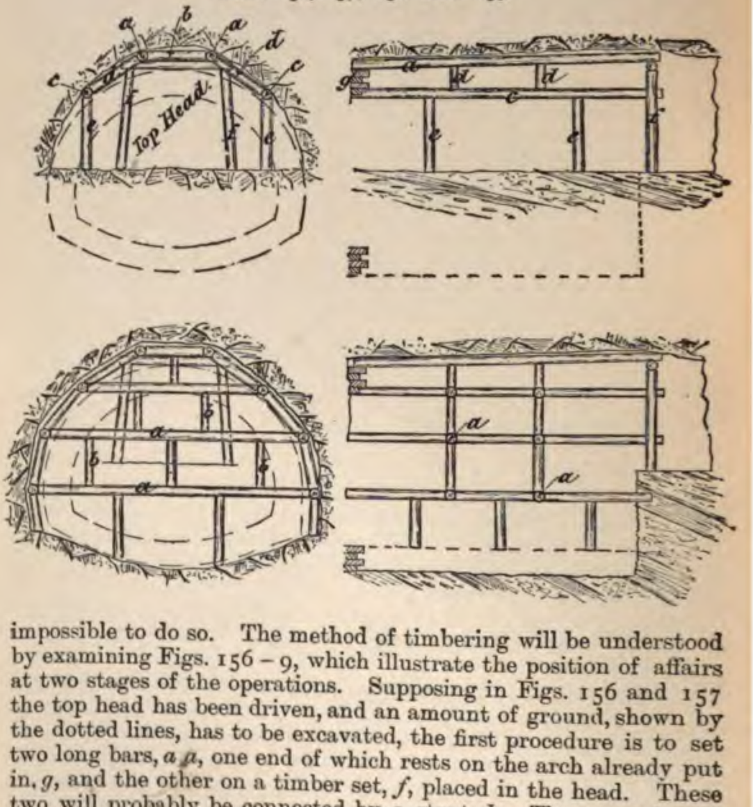
shown in Figs. 154 and 155. They do not contain any straight lines. In the 12 ft. arch, all the portion above the invert is part of a circle to radius 6 ft., while the 7 ft. arch contains portions of four circles—*i.e.*, the two side walls and invert to radius 7 ft., and the semi-circular upper part to radius 3 ft. 6 in.

These arches are put in in lengths, which vary with the nature of ground; 6 to 9 ft., with a bad roof, up to 5 to 7 yds., with a strong one.

The first procedure in putting in arches is to remove the ground; to do so, two methods are in vogue. In one—the general English custom—a small road is driven right at the top of the arch, and the ground excavated on each side and downwards, while in the other, the first road is driven at the base of the arch and the ground removed upwards.

In timbering the ground, the peculiar point is that all the main pieces are set *parallel* with the axis of the road, and not *transversely*, the reason for such departure from the usual practice being, that as the masonry is brought upwards all the timber has to be removed, and this could not be done, especially in the upper portion, where the two walls are approaching each other, unless it lay in the same line as the brickwork. Another point is, that if trees have to be set, as they frequently have, in the middle of the excavation, the *smaller* end should be placed downwards, the reason of this being that when the masonry in the invert is built round them, other props are set on the brickwork to the point they are holding up, and then those going through the masonry are drawn out, and if the larger end were downwards it would be impossible to do so. The method of timbering will be understood by examining Figs. 156 – 9, which illustrate the position of affairs at two stages of the operations. Supposing in Figs. 156 and 157 the top head has been driven, and an amount of ground, shown by the dotted lines, has to be excavated, the first procedure is to set two long bars, *a a*, one end of which rests on the arch already put in, *g*, and the other on a timber set, *f*, placed in the head. These two will probably be connected by a strut, *b*. The ground will then be excavated, first on the sides, and other longitudinal bars, *c c*, put in, connected to the other two by struts, *d d*, and behind these, lags will be placed if the ground requires it. At this stage Figs. 156 and 157 represent the position of affairs, the two longi-

FIGS. 156, 157, 158 AND 159.

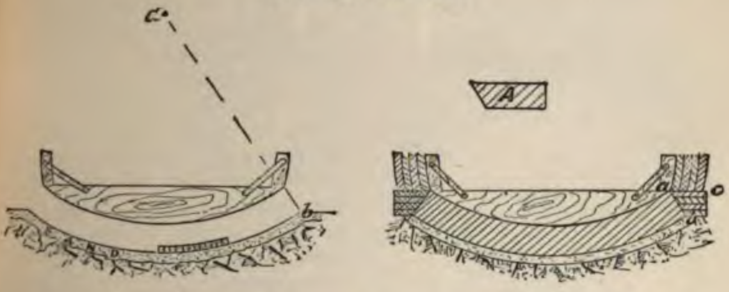


tudinal pieces, *c c*, being supported by small temporary props, *e e*, set on the floor.

As the excavation proceeds downwards, the props *e e* are removed, as soon as space is obtained for other longitudinal pieces. This process will be repeated until a complete lining, consisting of longitudinal bars and cross-struts between them, exists all round the excavation. In heavy ground the longitudinal pieces are often connected by transverse bars (*a a*, Fig. 158) and in addition vertical props, *b b*, are set between, until at the completion the work presents the appearance shown in Figs. 158 and 159.

The masonry is now commenced. First of all a lining of sand is spread in the bottom, and shaped to the curve of brickwork, of course at the proper gradient. A wooden frame or "template," made of the exact shape of the finished inside dimensions of the invert and side walls, is fixed at such a height above this sand as will allow the thickness of the brickwork which is going to be used to be placed between it and the sand. The first ring of masonry is generally laid dry. Operations commence at the centre line, placing the longer length of the brick parallel with it, and adding successive rows on each side until a point (*b*, Fig. 160) is reached. This distance is such that the ends of each ring when joined form a straight line, pointing towards the centre of the circle, of which the invert is part (*b a*, Fig. 160). The succeeding rings are put on by spreading a good bed of mortar over the one first laid, dropping the bricks down a few inches away from the position they will eventually occupy, and then slipping them along until they get into their proper places. By doing this, not only is the excess of mortar in the bottom pushed away, but a quantity is gathered up into the end and side joints, and, in addition, close contact between the mortar and brick is made. This procedure is repeated with each layer until all the invert is put in.

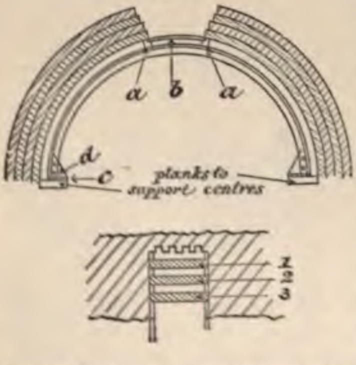
FIGS. 160 AND 161.



The building of the side wall now commences. The point *a b* (Fig. 161) is the weakest in the arch, so, as a compensation, the brickwork is increased in strength there (see also Figs. 154 and 155). With the exception of the small portion of masonry cross-shaded on the left-hand side of Fig. 161, all the brickwork in arches is laid in stretcher courses, but for this small piece English bond is used, and the bricks in each course are alternately at right angles to those of the invert, and, as they are laid horizontally, have to be cut into the shape shown enlarged at A. When the point *a c* (Fig. 161) is reached, the bricks are laid longitudinally again, but to obtain the proper curve, *culvert* or *arch* bricks are employed for the first course. Each ring is kept perfectly separate from the others, that is to say, they are not bonded together.

When the side walls have reached their proper height, the centres will be set, laggings put on, one by one, and the brickwork gradually brought round until the two sides nearly meet. To close up the top properly, the mason should be outside the arch, but as this is impossible in mines, the difficulty is got over as illustrated in Figs. 162 and 163. When the space between the two sides diminishes to about 2 ft., or such width as a man can conveniently work in, two grooved laggings, *a a*, are put on. Up to this time, the masons have laid the courses parallel with the direction of the arch, they now put the remainder in transversely, but still keep the longer axis of the bricks in the same direction. Commencing near the length already in, the man lays a strip of iron (*b*, Fig. 162 and No. 1, Fig. 163) in the groove of the laggings. He then makes up the small portion, supporting it on No. 1 iron, retires backwards, puts on another iron No. 2, and keys in the part between No. 1 and No. 2, goes back again, puts on No. 3, and repeats the process, until the length under consideration is secured.

FIGS. 162 AND 163.



Instead of using timber centres, which block up the upper portion of the road, the author has invariably employed iron ones, which possess the great advantage not only of being light and easily fixed, but also of leaving the centre of the road free. In some instances, they have been made from old railway rails, dropped into a wrought-iron shoe, or in others of angle iron, at the base of which a return plate about 6 in. sq. is placed (*c*, Fig. 162) and secured to the angle iron by a small gusset stay, *d*. The laggings employed are usually about 3 in. thick, and it must be remembered that twice the thickness of these has to be deducted from the diameter of the arch to find the size of centres required, therefore, with a 12 ft. arch, the centre should measure 11 ft. 6 in. With iron centres the author has put in over 100 yds. of 12 ft. arching in the main road of a colliery, and never stopped drawing through it a single day.

Arrangement of Inset.—In the great majority of cases, the empty tubs, after being removed from the cage, have to be brought back by the side of the pit shaft, and for such reason the hanging-on place is made wider than the diameter of the shaft, indeed, it is usual to provide a passage on both sides. The shaft brickwork and the arching are best connected by "belling" out the former, as shown in Fig. 164, this being by far the strongest construction, and, in addition, room is provided for bearers, to which either guide pulleys for haulage ropes or main supports for water or steam pipes can be attached. A sump frame, *a b*, will be provided to receive and keep the cage steady while changing is going on, and if two or more decks are used, another frame of cross-bearers, *c d*, will be put in. On the latter the cage rests during changing, and as it drops there with considerable force, Mr. Emerson Bainbridge has employed spiral springs at Nunnery Colliery, Sheffield, which are simply let into the bearers and receive the cage (Fig. 165). There are six springs to each cage, each 9 in. long by $5\frac{3}{4}$ in. diam., made with $9\frac{1}{4}$ coils of $\frac{3}{4}$ in. steel. All jar and shock is avoided.

FIG. 164.

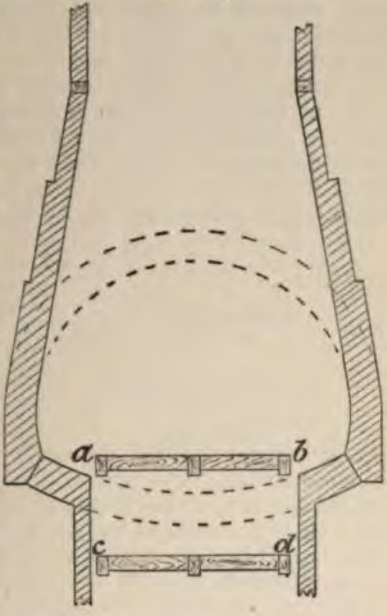
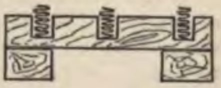


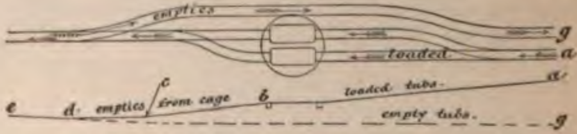
FIG. 165.



The arrangement of the tramways at the pit bottom should always be such that from the point where the full tubs are removed from the haulage ropes, to that where the empty ones are again attached, the motion should be due to gravity alone. To a certain extent, where engine power is available, it is, comparatively speaking, an easy task to haul the tubs to such a height above the hanging-on place that a regular fall is obtained towards the shaft for the full tubs, and a fall in an opposite direction for the empty ones. The landings are technically called "kips," and it is advisable that they should be as long as possible, so as to get standing room for a large quantity of tubs; winding may then go on, up to a certain limit, even while the haulage machinery is standing.

The question of caging the several decks simultaneously is treated of in Chap. IX., and all that will be done here is to describe the operation of getting the tubs (waggons) to the apparatus used for this purpose. The best plan is to arrange the shaft at one extremity of the main haulage road, and haul the tubs by mechanical means to the point *a* (Figs. 166 and 167); the full road is then laid at a slight inclination (about ½ in. to the yd.) towards the shaft, the tubs gravitate there, and are placed on the cage by an onsetter. The empty ones gravitate away from the shaft down the slope, *b c*, having a grade of 3¼ in. to the yd. to give the required speed, along a slight flat, *c d*, and then *up* the incline, *d e*. The tubs will not proceed far up *d e*, but do so for some distance, owing to the momentum they have gained coming down *b c*, and travel just far enough to clear the points at *d*. As the slope is against the tubs, their direction of motion is changed, and on their return down *e d*, they are switched off into a road to the left, having a down-hill grade, pass by the side of the shaft to the point *g*, where they are again attached to the haulage rope, and proceed into the workings. From the time the tubs leave the rope at *a* to the time they are again attached at *g*, no labour is necessary, the movement being quite automatic.

Figs. 166 and 167.



Mr. M. H. Douglas* has described, in an excellent paper, several systems of laying out shaft kips, all of which are worthy of study. One, however, needs special mention, where, owing to the inclination of the seam, caging takes place at two decks simultaneously, without the use of any balance arrangement (Fig. 168). There are two shafts, about 40 ft. apart, each sunk to the same seam, and two engine planes, each fitted up with a double line of rails. The coals hauled out of the No. 1 engine plane are drawn above the switches, *s*, and lowered down into the road, *x x'*, as required, and are hung on exclusively at the high level, the road

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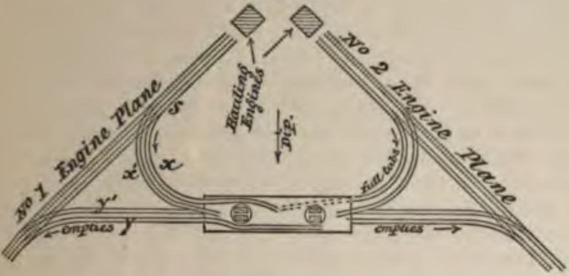
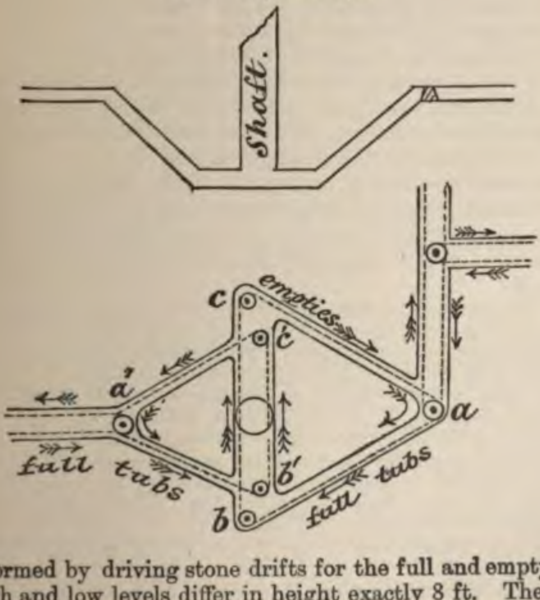
* Brit. Soc. Min. Stud. i. 443.

x being used for No. 1, and x' for No. 2 pit. In arranging the roads for the removal of the empties, advantage was taken of the natural dip of the seam, the road y being used exclusively for No. 1, and y' for No. 2 pit. The same method is pursued with the coals hauled out of the No. 2 engine plane, with the exception that these tubs are used entirely at the low levels, the gradient being formed by driving stone drifts for the full and empty roads. The high and low levels differ in height exactly 8 ft. The sketch explains itself, if it is remembered that the tubs from No. 1 engine plane feed the top decks of both pits, while those from

FIG. 168.



FIGS. 169 AND 170.



No. 2 engine plane feed the bottom decks. The only objection to such a system is, that equal quantities of material must be drawn by each engine plane.

The inset at No. 5 pit, Bascoup, Belgium, affords a fine example of the automatic and continuous movements of the tubs in o direction. The landing is laid with a double line of rails, and passes through the centre of the shaft, parallel with the longer axis of the cage (Figs. 169 and 170). From each end of it branc off two side roads, each laid with a single line of rails; one set proceeds towards the north, and the other towards the south. The two roads to the north, and the two roads to the south, rise from the shaft, and each pair unite at a point about 100 yds. above the level of the pit bottom, where the motive pulleys of the haulage are fixed. Roads branch off level to the east, and further junctions are arranged, as shown in plan (Fig. 170), each having separate wheels on vertical shafts. Two endless chains exist in the roads driven to the rise, one on each, and these pass round the motive pulleys. The full tubs descend towards the shaft in one road, and the empty tubs return from it in the other. The same chain passes upon pulleys on the upright shaft, *a a′*, and also round the return pulleys, *b b′*, *c c′*, situated at the two extremities of the inset, and passes through the shafts without interfering with the cages, or even with the movement of the tubs in the hanging-on place, as the tubs gravitate from *b* to *c*. The application is remarkably simple and efficient, a noteworthy point being that the direction of motion of the tubs is never changed, except at the working face. The plan explains this; the pit bottom occupies the lowest point, the dotted lines represent the chains, and the arrows the direction of motion.

Bibliography.—The following is a list of the more important memoirs, dealing with the subject matter of this chapter:—

MIN. INST. SCOT.: Report of Deputation *On the Method of Securing Roof and Sides*, iii. 51; *Propping at Straiton and Pentland*, Robt. Martin, xii. 58.

N. E. I.: *The use of Iron Supports in the main roads of mines instead of Masonry or Timbering*, G. Meyer and W. J. Bird, xxxvii. 135; *On the Introduction of Steel Supports for the maintenance of main roads in the mines of Cleveland*, A. L. Steavenson, xxxvii. 221.

BRIT. SOC. MIN. STUD.: "*Kips*" *or Landings at Shafts*, M. H. Douglas, i. 443; *Timbering in Mines*, H. St. J. Durnford, iii. 207, and W. S. Gresley, iii. 229; *Preservation of Timber*, ix. 76.

SOC. IND. MIN.: *Application du fer au soutènement des galeries à la houillère du Creuzot*, M. de Bianzat (2ᵉ Série), iii. 563; *Nouveaux systèmes de boisage*, H. Daburon (2ᵉ Série), ix. 873; *Blindage des galeries aux houillères de Rochebelle*, M. Gerrard (2ᵉ Série), xv. 391; *Effets de diverses préparations sur la durée des bois* (Comptes Rendus Mensuels), 1890, p. 223.

CHES. INST.: *Mine Timbering*, J. Clark Jefferson, vii. 270; *Shaft Timbering*, J. Clark Jefferson, viii. 209.

MID. INST.: *The use of Rolled Steel Girders for supporting the Roof in Mines*, T. R. Smith, x. 222.

CHAPTER VII.

METHODS OF WORKING.

The Two Main Systems.—Broadly speaking, there are two systems of mining coal, called "bord and pillar," and "longwall." Outside the North of England and Scotland the former is but little practised in this country, while the latter, which originally took its rise in the Midlands, is of very extended application. Endless modifications of each system are employed, and the two gradually merge into each other, until it becomes impossible to say to which system some methods belong. The tendency of the present day is to employ longwall more and more, and this method is slowly but surely superseding every other one. There are, however, some seams which it would be impossible to work longwall, that is to say, at any reasonable cost.

Shaft Pillar and Subsidence.—It is necessary that a certain area of coal around the shafts should not be worked, but should remain to afford support, and to prevent any risk of what is known as "creep." It is impossible to give any general rule by which the size of shaft pillars for given depths may be determined. Everything depends on the nature of the beds overlying the seam, the inclination of the strata, the nature of the floor and roof, and the question of stowing the excavation.

It is hard to prevent creep in seams having a soft floor, especially if water is present. The pressure on the pillars of coal forces up the soft underclay in the roads between the pillars. When once this action commences it is most difficult to stop, or to keep the roads open; everything seems to be on the move. Perhaps the only method of prevention in longwall work is efficient and close packing; leaving large pillars is not sufficient, as Mr. J. A. Longden* mentions an instance of a Derbyshire colliery, 520 yds. deep, where the shaft pillar was 260 yds. broad by 800 yds. long, the mine being flat, and yet creep came on so seriously that great fears were entertained that the shaft would be lost. The pit bottom arching had to be put in three times, finally with layers of oak and brickwork alternately.

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* Brit. Soc. Min. Stud. xii. 127.

The working of beds of coal always lowers the overlying strata, giving rise to what is known as "subsidence." A certain height is taken out, and, although the excavation may be filled with material, such packing, even at the best, is loose compared with the solid coal originally existing. The gob is compressed, and the overlying strata and the surface sink down. If the area of subsidence was limited to the strata immediately above the area worked, the problem of determining its direction, if not its amount, would be easy, but even in level measures the disturbance extends beyond the limit of the excavation.

With inclined seams the fracture of the beds *never* takes place in a vertical direction, but always in a plane approaching the perpendicular to the inclination of the strata. M. Callon[*] advocated the theory known as the "Normal," that subsidence takes place at right angles to the planes of stratification, and extends, without sensible diminution in amount, right up to the surface, whatever may be the depth of the beds. M. Dumont,[†] after an exhaustive examination of the district around Liége, expressed a similar opinion, but the Colliery Owners' Association[‡] afterwards drew up a reply, advocating that "the law of the Normal" does not hold good where the strata are highly inclined. The whole subject was reviewed by M. Fayol,[§] who, in addition conducted numerous experiments. He points out that the theory of the Normal is based on the erroneous supposition that beds *break* at right angles to the planes of stratification, and at the perimeter of the excavation; but, from actual experiment, he found that the plane of fracture is a more or less inclined one. After describing numerous experiments made on elaborate models, and instances of the result of mining operations, M. Fayol[‖] states that in stratified deposits the zone of subsidence is generally limited by a sort of dome, which has for its base the area of the excavation.

If the beds are horizontal, the dome is arranged symmetrically round its axis, which is vertical. Each of the beds included in the dome sinks in the form of a basin; the extent of the movement diminishes in proportion as it is further from the centre of excavation. If the beds are inclined, the dome is no longer symmetrical, and its axis is inclined.

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[*] *Lectures on Mining* (English translation), ii. 306.

[†] *Des affaisements du sol produits par l'exploitation houillère*, Liége, 1871.

[‡] *Des affaisements du sol attribués à l'exploitation houillère*, Liége, 1875.

[§] *Note sur les mouvements de terrain provoqués par l'exploitation des mines*, Soc. Ind. Min., 2^{e} Série, xiv. 805.

[‖] This paper is the most important one which has been published on the effect of coal-working on the surface, and throws considerable light on what is perhaps the most intricate problem in mining, and about which few facts are known. A careful extract from it, and also of M. Dumont's memoir, by Mr. H. F. Bulman, is given in Jour. Brit. Soc. Min. Stud., vol. xii.

In proportion as the seams become more inclined, the axis of the dome is inclined also, and tends towards the horizontal; at the same time the *height* of the zone of subsidence tends towards zero. The axis of the zone of subsidence is quite independent of the vertical, and of the normal to the strata. Vertical, normal, axis of figure of dome, and line of maximum subsidence, all coincide when the beds are horizontal; they are distinct when the beds are inclined.

When the zone of subsidence crosses several groups of beds at varying inclinations, the axis of the dome is deflected in passing from one group to another, and approaches to the normal of the group in which it is. Thus, for example, in beds disposed in the shape of a fan, commencing with the horizontal, the axis of the zone of subsidence, starting from the vertical, arrives by degrees at the horizontal. The direction of the axis of the zone of subsidence must not be confused with that of the limits of this zone (*i.e.*, the circumscribing lines of the dome). Sometimes the axis approaches in a remarkable manner the perpendicular to the strata, and it is this perhaps which gave rise to the theory of the "Normal."

From the above considerations it follows that, when the seams are inclined, shaft pillars require to be much larger on the rise side than on the deep. The occurrence of faults must be carefully noted, as, where they cross the area affected the lines of fracture are deflected and proceed along them; sometimes they extend, and at others diminish, the area of surface affected.

Where the regular beds are covered with a layer of soft, loose, sandy material, the area of subsidence may be unlimited, especially if the deposit contains water.

Mr. Longden* recommends for level seams the leaving of one yard in breadth for each yard in depth, that is, a shaft 200 yds. deep, should have a pillar 100 yds. radius or 200 yds. diameter. This seems a large amount, but the error, if any, is on the safe side.

Arrangement of Labour.—Before describing the methods of mining, some reference should be made to the two systems under which the labour is carried out. In one, the miner not only gets the coal, but carries out odd work, such as packing, repairs to roadways, &c., while in the other, a skilled class of colliers are employed simply as hewers at the face, all dead work being performed by separate staffs of men. In the latter system, the labour is subdivided, each class of men carrying out special duties.

If the hewers are employed solely at the face, a larger tonnage is produced per man, and hence less extent of workings is required, with a corresponding reduction in the cost of maintaining a smaller area under timber. The face moves faster, the weight has less time to break up the coal, the roof is always "green" (or fresh), and there is consequently less liability to accident.* Except under special circumstances, coal is invariably mined cheapest where the face travels fastest; the exception is, a seam having a very strong roof and floor, as here it is possible to move too fast.

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* *Ibid.* xii. 128.

The division of labour does not actually produce more coal with fewer men, for other colliers have to be employed to perform the work the hewers originally did. The old out-put is, however, produced from a smaller extent of workings; and, on an average, about one-half of colliery cost accounts are capable of reduction in proportion as the output is increased, and the area from which it is produced is reduced. So far as maintaining roads is concerned, the chief point is to see that the gob is carefully packed, and that all props are removed, so that the roof can settle, and not break down.

The above observations do not apply so strongly except in such places where, from the nature of the roof, and the seam itself, the amount of repairs is large, and keeps the miner away from the actual coal-getting for a considerable part of his time. Timber drawing is, certainly, best performed by a separate staff of men, who should, preferably, be set the work by contract.

Bord and Pillar Working.†—After driving out the main roads the first operation is to divide the coal into a series of rectangular blocks (Fig. 171), by means of drivages, called "bords" and "walls," the line of the latter being generally spoken of as "headways course." The bords are driven from 4 to 5 yds. wide, and always in a direction at right angles to the cleat of the coal, or, as it is generally termed, "on the face." Headways course is at right angles to these, or, in other words, parallel with the cleat, and as this runs approximately north and south in the North of England coal-field, headways course is generally taken to mean north and south, and bordways east and west. As a rule, walls are driven about 2 yds. wide, but sometimes both bords and walls are driven 5 yds. wide, and the roof allowed to fall.

The first procedure is to drive out the main roads. At large collieries there are usually four proceeding at once, two intakes and two returns. Before these roads have gone far, bords and walls can be commenced on either side of them, leaving, however, sufficient coal on both sides to prevent any risk of creep. At one time, the pillars which were cut off by the bords and walls were made only just large enough to keep the roof up, and were left. This has been quite abandoned, and the pillars are now made very large, quite a common size being two, and often three, chains square. In addition, as soon as these pillars have been formed, their removal is commenced, while the driving of bords still proceeds only a short distance away. In this manner the percentage of large coal has been materially increased, and the pillars are scarcely crushed at all, which is especially noticeable where both the coal and roof are tender.

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* So. Wales Inst. xv. 114.

† Also known as "post and stall," and in Scotland as "stoop and room."

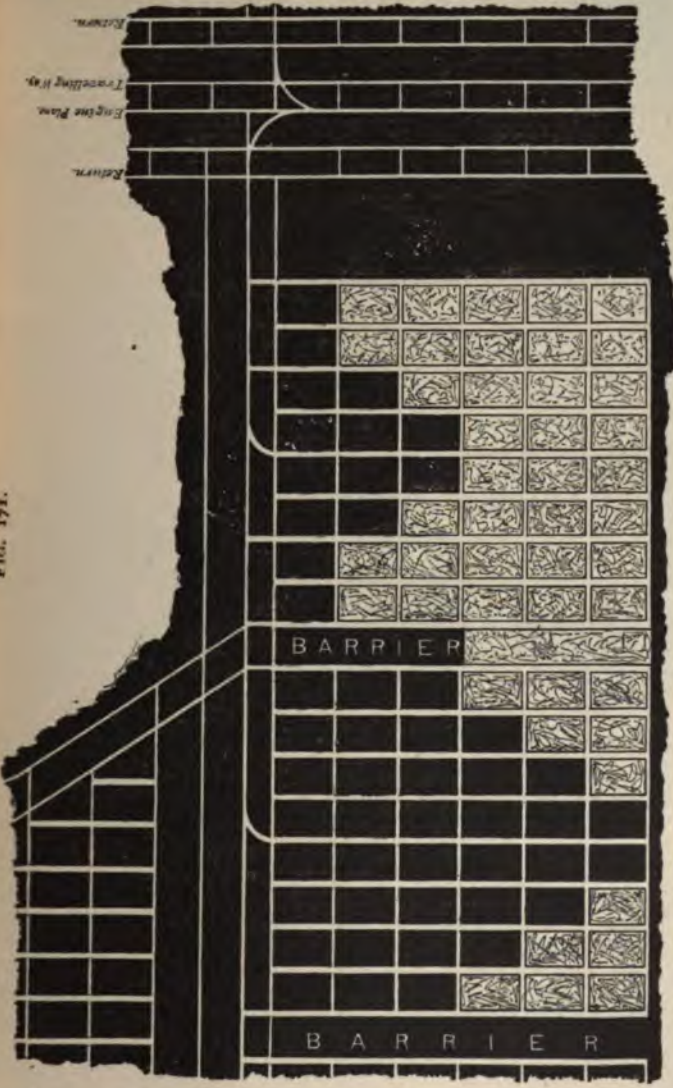
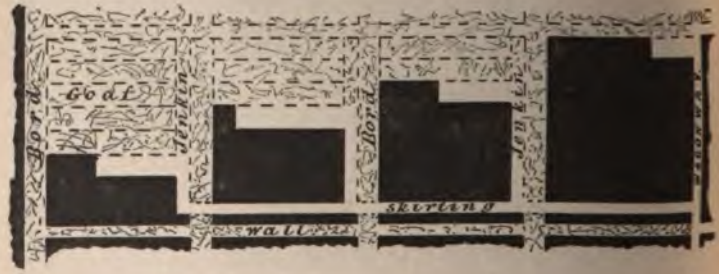


Fig. 171.

Another practice, which was introduced by the celebrated viewer Buddle, about the beginning of the century, is the method of dividing the colliery up into what are known as "panels," or "districts" (Fig. 171), these consisting of an area of from 30 to 40 acres, surrounded on all sides by a rib of coal, called a "barrier," these barriers being holed through at points where roads are necessary. This system of panels is particularly advantageous with a tender roof and soft floor; only a small area of the seam is opened at once, the roof does not weight so badly, nor require so much timber, and more round coal is produced. In addition, the risk of creep is, to a certain extent, prevented, or it may be confined to the panel in which it arises. The risk of explosion is decreased, as each district has its own current of air, and should anything happen in one, there is little probability of it extending to the others.

The preliminary work of driving the bords and walls is called "working in the whole," the removal of the pillars, which follows afterwards, "working in the broken." In the latter a proper line of operations, usually a diagonal one, should be adhered to, as if portions of a pillar lag behind, or become surrounded by broken workings, the coal is very much crushed, and quantities are very often lost.

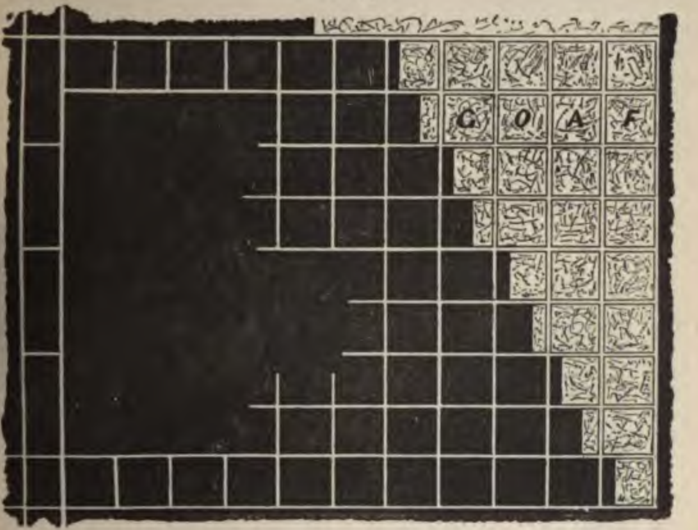
FIG. 172.



The removal of the pillars is carried out by a series of drivages, technically called "jenkins" and "skirtings"; the former is a place driven in a pillar in a bordways direction, while the latter is a similar place driven headways way, although, as a rule, any place driven alongside the fallen roof is called a skirting. At Eppleton Colliery the pillars, which are 44 yds. by 33 yds., are worked by driving a fast skirting out of the waggon-way, the length of four pillars, as shown in Fig. 172, leaving 6 ft. of coal against the fallen roof in the headways. A jenkin is then carried up the pillar alongside the old bords, and then lifts or "juds" are driven right across, these being 5 yds. wide. As soon as one of these reaches the fallen roof on the west side of the pillar, a second is commenced out of the jenkin. Several pillars are attacked at the same time, the lifts in each lying back in step fashion, as shown. The roof is kept up in the juds by a series of chocks or cogs, formed of timber 22 in. long by 4 in. square, placed 4½ ft. apart, and, say, 6 ft. from the coal side. The space between the loose side and the chocks is secured by ordinary props and laggings, these, except three rows at the face, being drawn every night and the roof allowed to fall behind.

At the same colliery, with large pillars 66 yds. square, the process of removal is carried out by driving a jenkin up the middle, splitting the pillar into two halves, and then taking 5 yd. lifts right and left. This is the system recommended by Mr. G. C. Greenwell. If the pillars have in the first instance been made large enough, he says the whole of the wings on each side may be brought back simultaneously, chocks being used in double rows for the support of the roof, the back row, or that next to the gob, being shifted between the front row and the coal as the face advances.* The system of working, and the method of removing the pillars, have been described by Messrs. R. A. S. Redmayne and H. F. Bulman in two excellent papers, to which the student is referred for further particulars.†

FIG. 173.



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* *Mine Engineering*, p. 200.

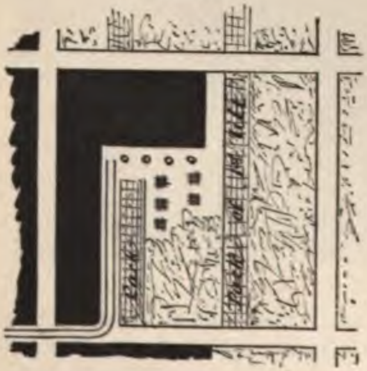
† Brit. Soc. Min. Stud. ix. 101 and 174.

The objections to the bord and pillar system are the difficulty of ventilating the workings, the amount of coal which is lost (a thin piece has always to be left on the sides of the bords and walls which are fallen), the smaller percentage of round coal produced, and the large charge for narrow work; not only are the bords and winning headways in the whole paid for, but the skirtings and jenkins in the broken are also subjected to a yardage rate.

Lancashire Method.—In the Lancashire coalfield, with steep seams dipping 1 in 3 to 6, a system is employed resembling both bord and pillar and longwall. A pair of roads are generally driven from the shaft direct to the deep, and out of these, levels, 30 yds. apart, are driven to the boundary (Fig. 173). Each pair of levels are somewhere about 200 yds. apart, and the coal is left solid between. On reaching the boundary, two sets of levels are connected by a road, and the coal between is divided up into pillars by a series of drivages crossing each other at right angles. All the pillars are not cut off before commencing to remove the coal, but are gradually formed, leading the face as shown by the illustration.

The pillars are removed by lifts taken uphill. These lifts vary from 12 to 15 yds. wide, and are taken forward like a longwall face. A line of rails is carried by the side of the solid coal, and a pack-wall built on the other side (Fig. 174). Two rows of chocks, about 2 yds. apart, are always kept parallel with the face, and at the same time a third row, 6 ft. further back, is being withdrawn, trees or props being set all round them while such is being done.

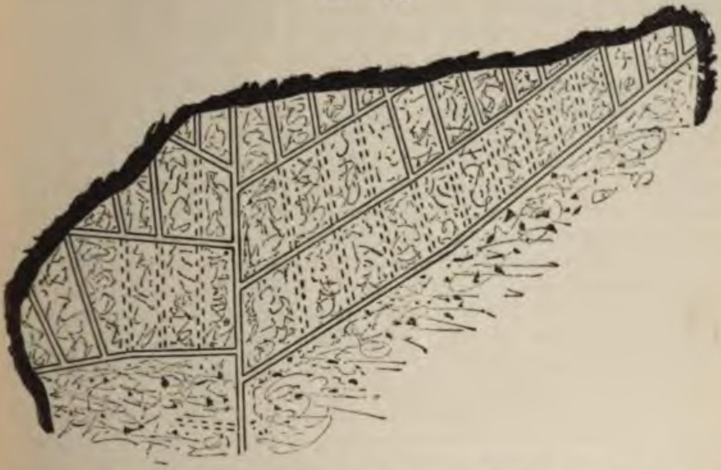
FIG. 174.



In some instances the pillars are cut off much larger, and are removed by lifts as before, but here several proceed at the same time, one leading the other, the face having a stepped appearance similar to Fig. 179.

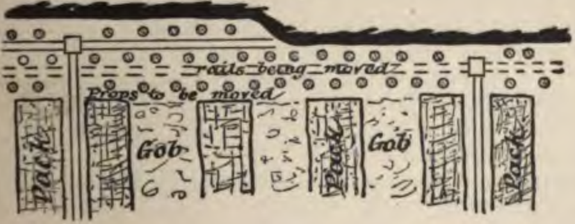
Longwall Method.—In this system the coal is extracted in a long face, which is gradually moved forwards. The space behind the working is filled in with packing, and what are called "stall roads" are made into the face at intervals. These stall roads are cut off at regular distances by levels, generally branching obliquely out of the main roads; by such means the length of gob roading to maintain in repair is kept within reasonable limits, and, in addition, the distance which the coal has to be hauled is reduced. This is the ideal longwall, and its carrying out in practice is well represented by Fig. 175, which is a reduction of a portion of the working plan of a colliery. The working roads through which coal is drawn are shown in full lines, while those which have been cut off and abandoned are represented by dotted ones.

FIG. 175.



The system of working is very easy, the miner undercuts the coal all along the face, supporting it in the meanwhile on sprags. The roof at the rear of the workmen, where the coal has been got down, is generally kept up by a double row of props, those in one row alternating with those in the other. Behind these comes the goaf pack. When the sprags are taken out, the coal is either shot down or falls on its own account. It is loaded up into tubs, a line of rails being laid along the face; the rails have to be taken

FIG. 176.



up and relaid with each advance. The details between two stall roads are shown in Fig. 176.

Perhaps a more vivid impression is given by the two photographs (frontispiece) taken in the mine by Mr. A. Sopwith, who has kindly allowed their reproduction here. The upper one shows the miner holing the face, with a cocker sprag on his right hand. The other is a view up the face, which is holed and ready to be got down, the miner in the foreground being engaged in drilling a shot-hole. The line of rails and cogging are clearly shown.

The weight naturally comes on along the line of face, and when this is continuous, as in Fig. 175, it is sometimes very expensive to maintain. In such cases, the stalls are often arranged to lead each other a short distance (Fig. 179). If the mine is level, the stall roads will be brought into the middle of each wall, but with inclined seams, they will be carried nearer the deep side, as this facilitates the removal of the coal. When the stalls are so arranged the weight is localised, and prevented from spreading all along the face. Several disadvantages are, however, introduced: supervision is rendered difficult, undercutting is not so convenient, one cutting side is introduced, and machines cannot be employed. In addition, the pressure on the sharp corners is great and breaks up the coal there, producing a large quantity of small.

As a rule, the seam itself does not supply sufficient material to fill up the whole width across the face, and in such cases, the packs are built leaving what are called "wastes" between. In seams liable to gob fires, the packs are best set draught-board style—*i.e.*, first a waste and then a pack, each waste being successively closed by having a pack built in front of it, wastes then being formed opposite the back row of packs. In this way, although the gob is not stowed solid, yet a continuous stopping of pack material is built across the face.

The stowing material is obtained, not only from the stall roads, but also from the main roads. As the gob gets compressed, the roof sinks down, and the roads become too low to allow the passage of men and horses. Recourse has to be made to what is known as "ripping," which consists in shooting down the roof stone until sufficient height is obtained. Part of this is always built on each side of the roads, while the remainder is carried into the face, and used there.

The direction of the face is determined by several conditions. In some districts, divisional planes or "cleat," exist in the coal; they usually cross each other at right angles, but one set is always much better developed than the other. If the working face is parallel to the main cleat, the coal is said to be "on the face," if it is perpendicular to the cleat it is called "on the end," while if another direction is followed, and the face advances obliquely at an angle of 45°, it is said to be "half on."

The main object of working coal is to produce the greatest quantity of large coal in the best condition, and this quantity and condition are materially influenced by the direction of the face respecting the cleat. In a longwall face, owing to the compression of the gob, there is always a considerable amount of weight on the coal at the face; such pressure, indeed, in many instances, gets down the coal without the aid of explosives.

If the coal is worked "on the face," the lines of fracture produced by the above-mentioned force coincide with the lines of cleat, and consequently the coal readily breaks. If the coal is a good strong hard variety, the labour of getting it is reduced, and the quantity of large coal is satisfactory; but if, on the other hand, it is soft, a large amount of small coal is produced. In such cases, it is far better that the coal should be got perpendicular to the cleat, or "on the end."

The direction of the face is, however, influenced by another point, namely, that of the inclination of the seam, which, in many cases, determines the direction irrespective of other considerations. In longwall workings, where the inclination is moderate, the direction of the face is generally at right angles to the dip, as all the weight is then thrown back on to the gob, the packs are easily and readily made, and the coal descends from the working places by the influence of gravity. Where the inclination is steep, the face will be carried half on, that is to say, at an angle of 45° with the inclination.

The length of the stalls, or the distance between two roads, is governed by a variety of circumstances:

(1) If the coal is to produce its best yield and be worked economically, it is advisable that the face should move forward regularly every day, but if such is to be done, the distance between two stall roads must not be too long. In the Midlands, from 30 to 50 yds. has, by general consent, been found to give the best results.

(2) On the other hand, the distance between the stall roads must not be too short. The more these roads are multiplied the higher is the expense of maintenance, because a greater length has to be kept open, and a further charge for the larger quantity of ripping required is also incurred.

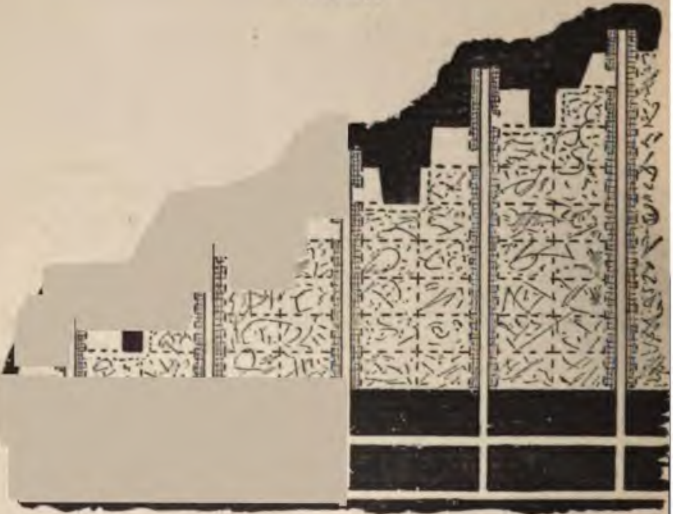
(3) The coal has to be got out of the face into the roads, and unless the height in the stalls is such as will allow tubs to be brought in and loaded there, it is advisable that the stall roads should be as near together as possible.

(4) The stall roads must not be too far apart, as it is only possible to have two tubs in the stall at the same time—*i.e.*, one from each end. For a large out-put it is, therefore, necessary to either multiply stalls or decrease their length.

(5) The length of the stalls is also influenced in a very marked manner by the custom of the coalfield, as to whether the men work singly or in sets. In the Midlands four or five men take a stall, and consequently its length is somewhere about as before

stated. In the North of England every man is for himself, wh necessitates the roads being close together, with a multiplicity working faces; indeed, a common arrangement is that shown Fig. 177, which can scarcely be called true longwall at al Headways are turned out of the main roads at intervals of 30 yd and after they have been driven 10 yds., lifts 8 yds. wide are tak right and left, and carried 15 yds. up, or half the distance betwe the headways. A line of rails is laid next the coal side, and a ro of chocks on the other side. After the first lifts are driven up few yards, the winning places are widened out to 6 yds., an

FIG. 177.



driven forward this width, stone packs 6 ft. wide being built each side, leaving a 6 ft. road between.

By general consent it is now admitted that in longwall eve piece of coal, except the shaft pillars, should be taken out. A one time it was pretty common to leave pillars of coal on each si of the main roads, which were supposed to reduce the cost repairs, and no doubt did so when the mines were shallow. A they got deeper it was found that such pillars offered litt protection, unless they were made inordinately large, and th better results were obtained by taking out the coal altogether.

The method of working that has been considered—viz., workin away from home, and carrying the roads through the gob, is t

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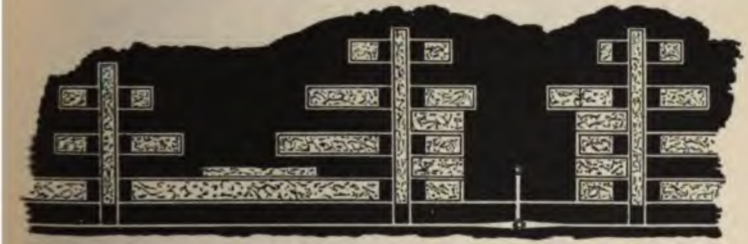
* Brit. Soc. Min. Stud. x. 192.

one followed in the great majority of cases; but another method, called "working homewards," is rarely employed, although it is often recommended as a cure for all evils relating to explosions. In it roads are driven out to the boundary, the coal first worked there, and gradually brought back towards the shaft, leaving all the gob, water, gas, &c., behind. It is scarcely necessary to say that, with anything like a large royalty, such a plan would involve the outlay of an enormous sum of money, as all the yardage in narrow work would have to be paid for practically before any coal was won. The output of the colliery would be a low one for many years, and the interest on capital outlay would more than compensate for any saving resulting from the smaller employment of timber and repairs. In small isolated cases, under special conditions (such as an exceptionally bad roof), the method of working homewards is applied with much success.

Double Stall Method.—In the South Wales coalfield a system largely employed for mining steam coal is that known as the double stall. In the ordinary system of opening, the two main roads will be set away, and out of these side-headings in pairs will be opened out to the rise, taking out the coal between. From these cross-heads double stalls are driven (Fig. 178).

FIG. 178.

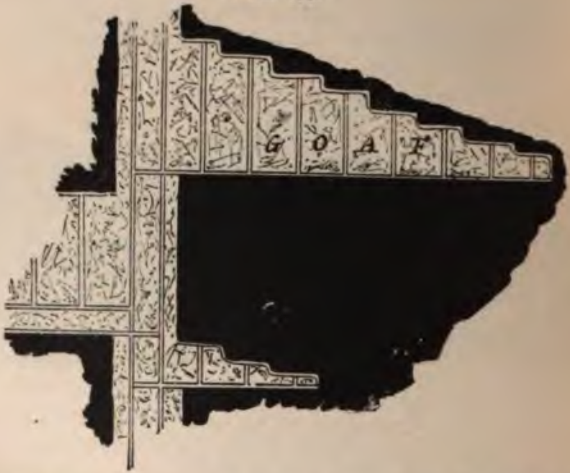


Two headings are commenced off the roads, and, after proceeding from 8 to 10 yds., are joined, and continued on as a double stall, usually some 20 yds. wide, having a road along each side, and a rib of coal from 12 to 15 yds. between each pair of stalls. The stall from one cross-heading meets with the opposite one from the other cross-heading, and as soon as this happens the two men, who were working at the face, separate, one going to the right and the other to the left hand, each working back half the width of the rib. The other half is taken out by the adjoining stalls, and consequently the ground is quite cleared.

It is a system which is being replaced by longwall in the South Wales district, but at the same time, one which is replacing pillar and stall, in some instances, in the Northern coalfield.

Working Steep Seams.—Steep seams may be worked to the deep, which allows an easy stowing of rubbish, and results in a saving of pit work. Sinking shafts and cross-cutting measures is very expensive, and only a small area is won; but if a main engine plane is driven straight down, it can be extended at any time with additional engine power. It has been proved by actual experience that from 8 to 10 per cent. more round coal is produced by working to the deep than working to the rise, which is probably accounted for by the fact that the weight is thrown off the face in working to the deep. It, however, possesses disadvantages if water be present, and an additional one in that the gradient is always against the load. In rise workings gravity brings the coal down to the levels, where it can be collected into sets and hauled along the main engine plane, but additional labour is necessary in self-acting planes.

FIG. 179.



In some parts of the Bristol coalfield,* where the measures are steep, the area is sub-divided into a series of panels, and everything worked to the deep. Each bank has a separate engine and engineman. The system is costly, but under certain conditions and no water, is safe and produces coal in good condition.

Perhaps the best way is to win the coal by an engine plane driven straight to the deep, and as this is in advance of the workings, all the water is collected there and pumped to the shaft. Levels, right and left, are branched off at intervals at about 100 yds. and the coal worked to the rise (Fig. 179). Self-acting inclines bring the coal to the level, which is then taken to the engine plane and hauled to the pit bottom.

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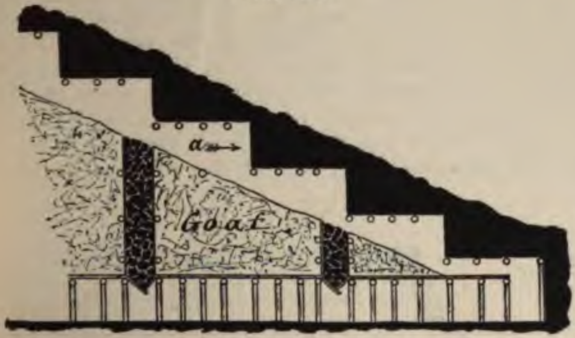
* So. Wales Inst. xii. 363.

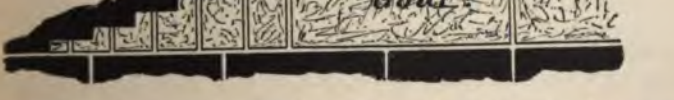
On the Continent, where the seams are not only highly inclined but very much distorted and broken up, the general practice is to sink a vertical shaft, and drive cross cuts at regular distances apart. At the points of intersecting the seams, levels are taken right and left. These are driven along the strike of the bed, and as the inclination is anything but a regular one, are usually very crooked.

FIG. 180.



In the thin, very highly inclined seams, the coal between the successive levels is removed by the method known as "gradins renversés," or inverted steps (Fig. 180). The face is divided into a series of steps, and advances in the direction shown by the arrow, *a*. There is one workman to each step, and he chips away the vertical face of coal before him, having the solid coal above his head. Shoots through the gob convey the coal to the lower level. The method of timbering will be understood from the illustration.

FIG. 181.

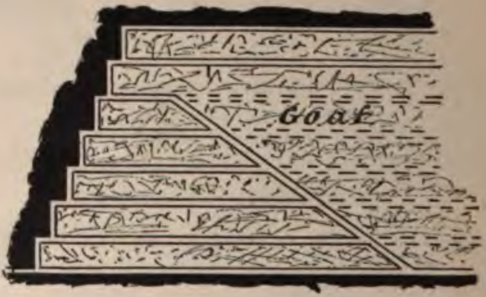


The system of working is in every respect identical with that known to the metal miner as overhand stoping.

In the more moderately inclined seams, say up to 40°, the method called "tailles montantes," is employed (Fig. 181). It is a system of pure longwall. A number of stepped faces, about 20 yds. wide, are carried up about 4 or 5 yds. in advance of each other. Each stall is served by a road kept through the gob, but these are cut off every 55 to 65 yds. by a horizontal cross-level.

The more moderately inclined seams are worked by the system called "tailles chassantes" (Fig. 182). A road is carried up from one level to the other, and branch roads put off right and left, about every 15 to 20 yds., measured along the inclination of the seam, taking out the coal for a distance of from 50 to 100 yds. on each side of the main incline, the face, as before, presenting a series of steps; at intervals, diagonal roads are put up through the gob, cutting off the level roads as illustrated.

FIG. 182.



The extra cost of working steep seams is considerably larger than moderately inclined ones, probably as much as one half more, in some instances frequently a third.

Working Thick Seams.—South Staffordshire.—No matter what system of working is adopted, the invariable rule in the Ten-Yard seam is to drive out to the boundary and bring back the work, leaving the gob behind. Two main gate-roads proceed along the strike of the seam, serving as haulage roads, and the distance between them varies from 33 to 45 yds., being always such, that in the operation of getting coal, these preliminary drivages will form a portion of the chambers, and, as it is called, "come in to work." Where a large area is to be won, roads are branched out right and left of the main roads, and coal gotten at the extremity of these, even before the former have proceeded much past them, the only precaution to be adopted being, that the coal so worked should be a sufficient distance from the shaft not to affect it by any subsidence. While this portion is being worked out, the main roads proceed on their course, and branch roads are again sent out at suitable distances, and when they reach the boundary, either of the lease or of the district, work is opened as before.

The methods of working commonly employed may be divided into (*a*) square work, and (*b*) longwall, the whole thickness being removed at once. True longwall is, however, unknown in the thick seam. It might preferably be defined as bord and pillar, the large blocks being pillars. If so, the system of working is the same as the one pursued under the same title in the Northern coalfield; the removal of the pillars being similar with modifications occasioned by the greater thickness. The coal is sometimes worked in two divisions by a modified longwall system, but although this possesses some advantages, yet the numerous practical drawbacks, such as the increased quantity of small coal produced, the inferior mineral obtained when working the lower slice, and the frequency of gob fires, have resulted in its general abandonment, except in a few isolated special cases.

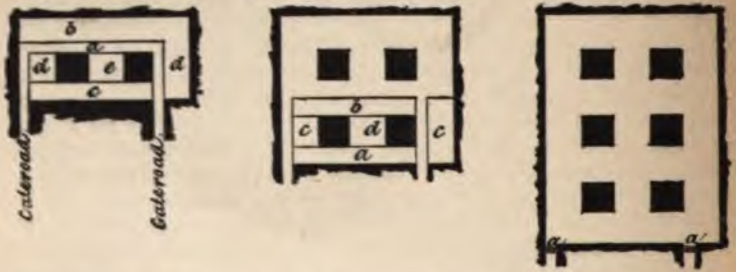
(*a*) *Square Work.*—In this system the coal is worked out in a series of rectangular chambers, separated from each other by ribs of coal, internal support for the roof being afforded by a series of square pillars of solid coal. The old method of opening a side of work was to drive a series of stalls 10 yds. wide, leaving 10 yds. of coal between each, and then a second set of 10 yd. stalls at right angles to the first, the result being that pillars 10 yds. square were formed. This operation would be carried out in the bottom coal, the top coal being got by the method described a little further on. Practically, however, opening a side of work in this way is a thing of the past. To do it with any success requires an exceedingly strong roof, and even then coal is not got out so clear as it should be. At the same time, it is advisable to drive the stalls, in the first instance, at least 5 yds. wide, and so save the cost of narrow work.

With an average roof a convenient size for the openings is 10 yds. wide, and for the pillars 8 yds. square, and in such case the ordinary gate-roads opening out a district will be driven, leaving a piece of coal 33 yds. wide between them. On reaching the boundary of the district the two gate-roads will be connected by a cross-drivage (*a*, Fig. 183). This will be widened out by "side-laning," which consists in treating the side of the road as a longwall face, and holing it out to a depth of 10 yds., as shown at *b*. While this is being done a second cross-drivage, *c*, about 5 yds. wide, will be carried between the two gate-roads, cutting off a block of coal 8 yds. wide. The side gate-roads will then be side-laned off to 10 yds. wide, *d d*, and a stall, *e*, driven through the block of coal remaining, the position now being that two pillars 8 yds. square are surrounded on three sides by openings 10 yds. wide, and on the fourth side by an opening 5 yds. wide. All this has been carried in the lower six or seven feet of coal.

In the back opening the top coal will now be got down in sections, slice after slice being removed vertically. The whole distance across this opening is not attacked at once, only a certain portion of its length being worked at a time. The top coal is got down by cutting vertical grooves up through the overlying measure of coal, leaving between each length of six feet what are called "spurns." These spurns are narrow webs of coal, holed through in the upper part. When the layer that is being attacked has been cut through in this manner on both sides, the spurns are reduced by the aid of a pick, and are then finally "jobbed" (knocked) out with a "pricker," which is a long instrument very similar to a boat-hook. A spurn is always left at the face, and when this is removed the whole mass falls, and is then in a position to be taken away by the loaders.

While this is going on a third cross-cut will be driven between the two main gate-roads at a distance of 13 yds. from the last one (*a*, Fig. 184). The opening *c* (Fig. 183) is then widened out to 10 yds., as shown at *b* (Fig. 184), the main road side-laned off as before, *c c*, and a middle thurling, *d*, 10 yds. wide, driven across, forming two more pillars 8 yds. square. While this is being done in the bottom coal, the top coal has been got down around the two pillars shown in Fig. 183. A fourth cross-drivage is made between the two gate-roads at a distance of 13 yds. from the last one, and the pillars there cut off, as already explained, so that at this stage of the operation the side of work considered will have the appearance shown in Fig. 185—viz., 6 pillars each 8 yds. square, surrounded by a series of openings 10 yds. wide. The top coal by this time will be removed all over the side of work, except on the three sides of the last two pillars, and will gradually be got down there until nothing remains. Fire-dams will then be put in at the points, *a a*, and a new side of work started, cutting off a rib of coal 8 yds. wide.

FIGS. 183, 184 AND 185.



(*b*) *Longwall in One Division.*—Gate-roads are first driven out 7½ ft. wide, leaving 40 yds. of coal between. The cross-holings are

The advantages claimed are: The greater first yield and total clearance of coal.

The disadvantages are: The large amount of slack produced (this being due to the quantity of gunpowder employed), and the smaller total yield per acre. A greater quantity is obtained per acre than by the first clearance in the square-work system, but, after the lapse of some considerable time, the ribs and pillars left in this latter method of working are cleared out. In many cases, the remnants of the thick coal are worked a third time, thus obtaining a further yield. The total produce of winning the broken is about one-third of the quantity obtained by the first working, of which one-third will be coal, and two-thirds slack. The expense of winning the broken mine is somewhat greater than that of getting the solid coal.

In every system of thick coal mining, dip work is advantageous, as the falling roof-stone rolls away from the workmen.

Pennsylvania.—The system of working the Mammoth Bed, which sometimes attains a thickness of 60 ft., as described by Messrs. H. M. Chance* and Franklin Platt† is similar to the double stall method of South Wales. Either from the bottom of the shaft or out of a slope, if no shaft is sunk, a main road, called a "gangway," is branched out following the strike of the seam. A parallel road some few (10) yards away, called a heading, is driven for the purpose of ventilation. When the coal is quite flat, the stalls, or, as they are called, "breasts," are opened at right angles to the gangway. Where the dip is too steep to allow a waggon to be used in the breast, if so driven, it is opened at an angle to the gangway, thus decreasing the inclination.

Two plans of opening such breasts are in common use. In one, the breast is opened at the gangway to its full width of from 8 to 12 yds.; in the other, an opening just wide enough for the waggon is driven from 8 to 10 yds., and the breast then opened to its full width. The inclination of the bed usually limits the length of the breast to 300, 400 or 500 ft., and coal lying at a greater distance from the gangway is mined from a second series of breasts, opened from a second gangway driven above the first series.

The distance to which the gangway is driven on each side of the slope, or, in other words, the lineal distance worked from a single opening, is limited by the cost of keeping the gangways open and the cost of haulage. If the coal is hard, and the roof good, it is often cheaper to mine coal lying two or three miles from the slope than to open a new one, but when the coal is soft, and the roof bad, it may be cheaper to open a new slope than to attempt to keep one mile or less gangway open.

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* Second Geo. Survey of Pennsylvania. Report A.C. *Coal Mining.*

† *Ibid.* Report A 2. *Coal Waste.* The chapter on Mining is by Mr. J P. Wetherill, and is an expansion of a paper originally contributed to Amer. Inst. M. E. v. 402.

The breasts are not worked through into the gangway above, but are driven up to within 5, 10, or 15 yds. of it; the pillar thus left is called a "chain pillar." When the breasts are worked out, the pillars are robbed by taking off from each as thick a slice as possible.

In very steep breasts it is impossible for a miner to keep up to the working face, as he has nothing to stand upon, and it is therefore necessary either to leave the loose coal in the breast or to erect some artificial support. A common method of opening out work in such cases is illustrated in Fig. 189. The breasts are opened by driving in two shoots for a distance of 8 to 10 yds., connecting them by a cross drivage, and then carrying the working forward its full width. Four strong props, *a*, are set just above the pillar so cut off, and against these, two log batteries are built, in each of which is left an opening, say 4 ft. square, that will permit large lumps to pass through freely. Roads are kept up each side of the breast by the use of inclined props, called "jugglers," which are notched into the floor and sides, and have 2 in. planking nailed against them (Fig. 190). The surplus coal may be drawn out at the bottom through the opening in the battery, but is more frequently sent down the man-ways; the loose coal is allowed to remain undisturbed until the breast is driven to the limit.

FIG. 189.

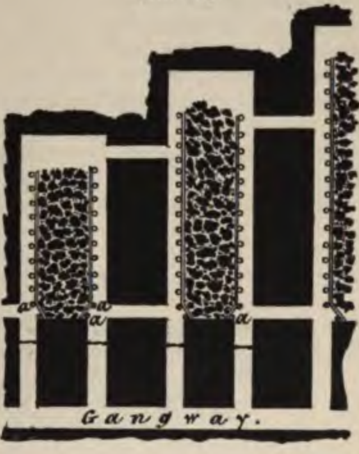
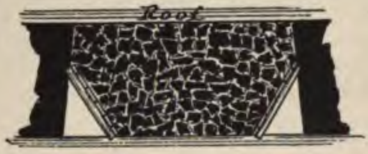


FIG. 190.

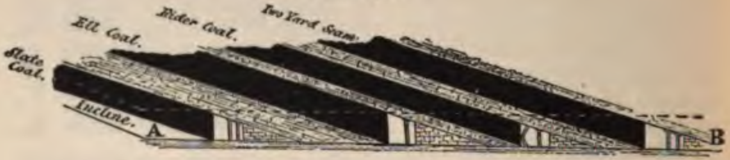


Working Seams Lying near Together.—In the South Staffordshire coalfield, when the distance between two seams does not exceed 6 feet, the general practice is to work the lower one first by longwall, carrying gob roads in the ordinary manner. When the boundary is reached the roads are ripped down into the upper seam, which is then taken back longwork towards the shafts. In many cases it is found that by such procedure the upper seam not only makes a greater percentage of large coal than it would have done if it had been cleared off first, but that the cost of production is less, as the undercutting is easier.

In the southern part of the Warwickshire coalfield all the seam come together, being only separated by a small thickness of partings, amounting to as little as 2 ft. between each seam. The method of working has been described by Mr. E. F. Melly.* A pair of dip roads are driven in the lowest of the seams to be worked to a distance of not less than 500 or 600 yds. A cross-drift is then cut through all the four seams (shown by dotted lines in Fig. 191), and they are each opened out by level headings to a distance of from 150 to 200 yds. on each side, cross-cuts at each end, and generally one in the middle, connecting the four seams for ventilation. In this way, eight different stalls, or working places, are at once made, each of which may be partly holed every day, so that 50 to 60 tons should be delivered to the flat, A B, from each one, and to this point an incline rope, which takes from 15 to 20 tubs at a time, delivers the empty tubs.

Each face follows behind the other, and as only a very short parting exists between the seams, there is considerable breakage, as the faces cannot possibly proceed at a greater speed than, say, 2 yds. per week, and as the distance at which the face of one seam lies behind another is about 10 yds., the coal in each case has only five or six weeks in which to settle down or deteriorate before being worked.

FIG. 191.



The main flat, A B, is made to last a long time, generally two or three months, and the faces adjoining the road are allowed to hang back a little, as making a new flat is rather an expensive business.

Spontaneous Combustion.—Some seams of coal are particularly liable to spontaneous combustion, the first signs of which are given by a peculiar smell, termed "fire stink." This undesirable state of affairs is produced by three agencies: (*a*) oxidation of the organic constituents; (*b*) iron pyrites; (*c*) pressure. The first is undoubtedly the main one, but is assisted materially by the other two.

(*a*) *Oxidation of the Organic Constituents.*—Richter's† experiments satisfactorily demonstrated the high importance of this action, and it may be looked upon as being the most effective of the three. Coal absorbs oxygen, one part combining with the carbon and hydrogen, forming carbonic acid and water, while the other enters into combination with the coal, and proportionally increases its weight. This alone would fix careful attention on this action, as it is found that, before combustion, coal so inclined emits large quantities of carbonic acid gas. Heating results from the absorption of oxygen, and absorption is favoured by heating, moisture, fine division, and absence of light; everything thus combines to favour decomposition.

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* N. E. I. xxxiii. 151; and Brit. Soc. Min. Stud. x. 104.

† *Metallurgy* (*Fuel, &c.*), Dr. Percy, 1875, p. 299.

(*b*) *Iron Pyrites.*—This substance on decomposing yields, first, ferrous sulphate, and, secondly, ferric sulphate; the former makes its appearance in the form of colourless fibres, protruding here and there from the face of the coal, while the latter is of a brown colour, and is more frequently observed. These products may suffer further decomposition, sulphuric acid being sometimes formed, and as their volume exceeds that of the original pyrites, disintegration of the coal is effected, together with a small heating in close proximity to each lump of pyrites. The heat generated is quite incapable of commencing a fire, but it may help, in a great degree, the action of other agents. Ferric sulphate is reduced to ferrous sulphate by contact with small particles of carbon, and hence may act as a carrier of oxygen to the organic constituents of the coal.

(*c*) *Friction from Slippings.*—Pressure from the roof on pillars cracks them, and grinds the irregular sides of these fissures together, thus producing heat and a considerable quantity of fine coal. Now, small coal does not absorb more oxygen than large coal, but it does so more rapidly, and the temperature rises very quickly. Really solid pillars never fire, it is only when they are being crushed that combustion occurs. The heat acting on the small coal produced by the grinding action, may also subject it to the process of slow distillation, and produce a quantity of bituminous matter, which, on the addition of further heat, suddenly bursts into flame.

Development.—The oxidation of iron pyrites cannot be looked upon as the primary agent in producing combustion. The amount of heat that would be given out by the oxidation of the quantity of sulphur in any coal can be easily estimated, and, on calculation, it is speedily recognised that this heat could not produce the results attributed to it, even if the pyrites existed in isolated nodules; another argument in favour of this is the very slow nature of the process; the heat produced is consequently dissipated, and only a small heating of the particles takes place.

There can be little doubt that the decomposition of iron pyrites is eminently favourable to spontaneous combustion; owing to the disintegration produced, it allows the coal to be more readily permeated by currents of oxygen, and, by the heating produced—small though it may be—favours the action of such currents.

When the first agent is considered, every circumstance seems to combine to render the action successful. Heating, moisture, and absence of light are all conducive to the oxidation of the organic constituents of coal; it is in seams most free from pyrites that spontaneous combustion takes place. The constitution of the coal seems to be of great importance; it is only in bituminous varieties that this undesirable state of things is found.

Little can be added to what has been already said on the heat produced by friction; the principal argument in favour of this view is the one already given—viz., if fire be found anywhere it will be in the cracks of pillars. No doubt this is perfectly true as regards some underground fires, but spontaneous combustion is frequently found occurring in heaps of coal above ground, and this coal may contain a very small percentage of pyrites. To account for the fire under such circumstances is impossible, unless the oxidation theory is admitted; and, in the opinion of the author, this action, in the majority of cases, is the primary agent, although either of the other two in conjunction may greatly facilitate it.

Prevention.—This can only be done by the loading up and removal of all fine slack and refuse. A vigorous current of cool air must be circulated through the workings, cooling the surface of coal over which it sweeps. The practice of reducing the quantity of air passing cannot be too strongly condemned; such procedure *increases* the risk of combustion, because sufficient air is always left for oxidation, and, owing to the small volume, the air gets heated higher than the surrounding strata, and consequently aids, instead of impedes, the risk.

There is a point at which a vigorous current of air is inadvisable; if combustion has broken out the quantity of air should be reduced, but until that point is reached a diminution in quantity only acts detrimentally.

In longwall workings, close and effective stowing of the gob with roof stone is the best preventive; if sufficient material is not available to completely fill the excavation, the packs should take the form of square cogs, and be arranged draught-board fashion. In thick seams, as there is practically neither roof nor sides to timber to in the workings, the only method of dealing with a fire is to isolate it by damming off the affected area.

If a fire occurs in a fast road, or in the gob in a thin seam, an attempt should always be made to dig it out. As an additional safeguard, lines of water mains are often laid along all the principal roads, these pipes being connected to the water behind the tubbing in the shaft. High pressure water is invaluable at collieries liable to spontaneous combustion; if a fire is attacked vigorously at its commencement it is often mastered, but when it attains fair proportions, it may not only occasion enormous expense, but be a source of continual trouble and danger.

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N. STAFF. INST.: *On Cleavage Planes, and their influence on the Economical Working of Coal*, G. G. André, ii. 132; *Mining in North Staffordshire*, J. Worgan, vii. 58 and C. Gordon, vii. 80; *On Pit Fires: a Consideration of careful Special Packing as a Preventive*, S. Spruce, viii. 38; *Method of Working Coal at Whitfield Colliery*, H. Wright, viii. 59; *The Erection of Stoppings, with a view to isolate part of a Mine on Fire*, A. R. Sawyer, viii. 100; *Gob Fires and Pit Stoppings*, R. Oswald, viii. 198.

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CHAPTER VIII.

HAULAGE.

Primitive Methods.—During the present century no branch of the various operations in coal mining has improved more than haulage. In the olden times, carrying the mineral on the shoulders of men or women was the method universally employed, and is still carried out in places where civilisation is imperfect. The practice is, however, adopted in one instance in our own country, where the conditions are such that any other system would be impracticable—viz., the ironstone mines of the Forest of Dean. The earliest improvement consisted in the introduction of sledges, which are now employed to a limited extent, for hauling coal from the working places in thin seams to the roadways, as it is impracticable to lay a line of tramway along the face. In the thin seams of the Somersetshire coalfield, where the coal is 14 to 16 in. thick, roads 4 to 5 ft. high are carried up to the face at distances of about 40 yds. apart, and along these tubs are brought. In the face the coal is loaded on to an ordinary plank about 12 in. broad, and 6 ft. long, one end of which is fastened to a piece of chain having a hook at the end farthest from the plank. The chain is passed between a boy's legs and the hook connected to a ring on a leather belt fastened round his waist. The plank is dragged to the way-end, and its load placed in the tub waiting there.

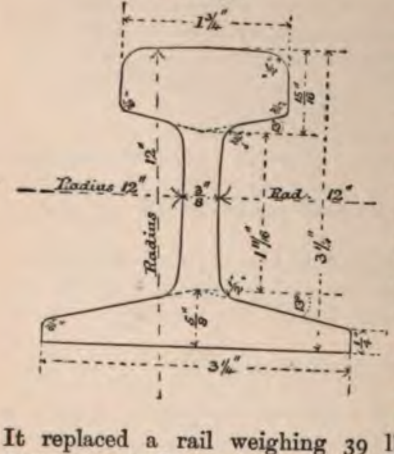
At this point, it may be stated, that it is a great advantage to have only one loading. Every time coal is emptied from one tub to another, breakage results, and, in addition, it costs money and labour.

Rails.—At the present time, practically all the rails used are of the flange pattern; bridge and angle designs having been abandoned. The sections employed have gradually got heavier, owing to the more permanent nature of the ways, and the desire to make haulage work as smoothly and with as few hindrances as possible. There can be little doubt that the wear of a rail is largely influenced by its composition, but the shape of the section and disposition of metal in the different parts is of greater moment. Using heavy rails does not necessarily ensure long wear.

The designing of rail sections has of late received considerable attention, especially in the United States, and several papers on the subject have been contributed to the Amer. Inst. M. E.* These refer to the heavier sections employed on railways, but are none the less true, if applied to the designs in use in collieries. The chief points brought out are, that the head should have as broad a wearing surface as possible, and should not be too deep. If too much metal is in the head, the temperature at the finish of the rolling process must be high, which produces a metal loose in structure that rapidly wears away in use. On the other hand, if the rail is finished by colder rolling, the compactness or physical hardness of the metal is increased. It is evident that the smaller the section the deeper will the effect of the compression of the rolls penetrate, and the finer will be the grain of steel.

The American Society of Civil Engineers appointed a Committee to draw out some standard rail sections, and a report of the progress made, has recently been published.† Ten different sets of designs were prepared, the following dimensions averaging as nearly as may be to the individual sections, if any wide deviations which appear in one set of sections only, be neglected: *Head*, 12 in. radius, top corner $\frac{1}{4}$ in., lower corner $\frac{1}{16}$ in., vertical sides, percentage of metal 41.5; *Neck*, $\frac{1}{4}$ in. top and bottom fillet radii, sides either straight or 12 in. radius (there appears to be a diversity of opinion on this point), percentage of metal 21.0; *Base*, 37.5 per cent of metal, width same as height of rail, sides vertical, with $\frac{1}{16}$ in. top and bottom corner radii, angle of head and top of base alike, 13 degrees (about $4\frac{1}{4}$ to 1). The width of the head is 0.54 and the depth of head 0.287 of the total height of rail. Fig. 192 shows a section of rail weighing 30 lbs. to the yard, designed on these lines, which the author is employing largely on main roads at a colliery where the total load of coal and tub is 25 cwt. It replaced a rail weighing 39 lbs., in which, however, the arrangement of material was bad. The disposition of the material

FIG. 192.



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* *Certain Conditions in Manufacture of Steel Rails*, F. A. Delano, xvi. 594; *Steel Rails and Specifications for Manufacture*, R. W. Hunt, xvii. 226 and 778; *A System of Rail Sections in Series*, P. H. Dudley, xviii. 763.

† Eng. and Min. Jour. li. 319, March 14, 1891.

so as to obtain the greatest wear with the least weight, is of the greatest importance, as the rail account at large collieries is quite enough without wasting more on putting steel into parts where it is not wanted.

Mr. P. H. Dudley[*] prefers to place the line of the radii for the sides of the web above the centre, so as to make the lower portion of the web thicker, for the following reasons:—To more nearly equalise the heat of the section between the base and the head, permitting colder rolling; to lower the neutral axis, better equalising the strain of the metal between the base and the head, and checking the tendency to permanent set; to check the tendency of the web to bend near the base of the rail under heavy traffic.

The following specification[†] is recommended when ordering from manufacturers:—

The section of rail, when rolled, shall conform to the template furnished; with an allowance in height of $\frac{1}{64}$ inch under and $\frac{1}{32}$ inch over permitted.

The length of rail shall be ...... feet; a variation in length of one quarter of an inch longer and shorter will be allowed.

The rails must be free from all mechanical defects and flaws, shall be sawed square at the ends, and the burrs made by the saws carefully chipped or filed off, particularly under the head and on the top of the flange.

The rails shall be smooth on the heads, straight in all directions, and without any twist or kinks, particular attention being given to having the ends without any drop.

The steel to contain as high a percentage of carbon as the makers are willing to put in.

In the working places the lightest weight possible of rails should be employed, just strong enough to carry the loaded tubs.

Length of Rails.—In the workings, the usual length is 6 ft., or sometimes 3 ft. when a longer length is inadmissible. The length should be such that the weight is small, in order that the workmen can easily move them about, as it is here that the greater quantity of rails are lost by falls. For laying the main roads no purpose is served by short rails, and for such situations, their length nearly approximates to those employed on surface railways.

Gauge.—The most general gauge is 24 in., although it varies from 18 in. to 30 in. With narrow gauges the operation of tipping the tubs sideways is facilitated; indeed, the objection to a narrow gauge is the ease with which tubs are overturned.

Methods of Laying Rails.—Two considerations have to be borne in mind here. In the working places, especially where the longwall system is used, rails are being frequently taken up and relaid in another position. This happens every time the face advances, and as a result, the way is not put down with much regard to evenness of road.

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[*] Amer. Inst. M. E. xviii. 781.

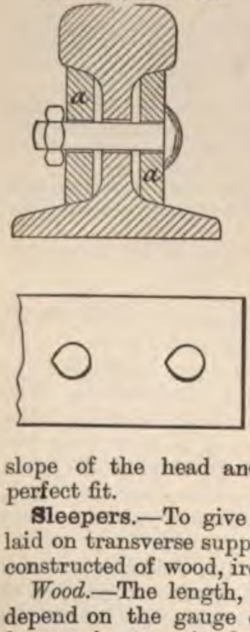
[†] *Ibid.* xvii. 238.

On the other hand, greater care is taken in laying the rails in the main road, because the line is a permanent one, and must be kept in good condition, in order that resistances to traction may be reduced to a minimum. Care is taken to make the gradient as regular as possible; the rails are kept perfectly straight, or, if curves are necessary, they should be bent by a machine similar to those used on railways. At many large collieries an experienced platelayer is employed, who superintends the laying of the main roads.

In laying curves, the gauge must be a little wider than on straight lines.

Fish-plating.—To obtain a rigid and straight joint on the main lines, side strips of steel called "fish-plates" are fitted on each side of the web (*a a*, Fig. 193) where the rails meet; holes are punched through the web and through each fish-plate, and bolts placed in them and screwed up tight. To allow for expansion, the holes through the rails should be oval, and to prevent the bolts turning round when the nuts are being screwed up, either the holes in one fish-plate are punched square, or the bolts made oval for a short distance under the head, and then round afterwards, or one fish-plate is punched with holes of a pear-shaped section (Fig. 194), and the bolt made of a similar form just under the head. The remainder of the bolt is made round, and, passing through the oval hole in the rail, permits the latter to move a short distance.

FIGS. 193 AND 194.



It is important that the fish-plates should be rolled to correspond with the slope of the head and top of the base of the rail to ensure perfect fit.

Sleepers.—To give the road a solid foundation the rails are laid on transverse supports called "sleepers," which may either be constructed of wood, iron, or steel.

Wood.—The length, breadth, and thickness of wooden sleepers depend on the gauge of the road and the weight of the load; from 3 in. to 4 in. deep by 6 in. broad is a common size. The wood employed is generally Scotch fir or larch; the former is cheapest in first cost, but the latter has greater lasting capacity.

To secure the rail to the sleeper, a hole is generally punched through the base, and a flat-headed nail driven through it into the wood. The objection to this is, that the hole weakens the rail to a very great extent, and breakages often result at the point where they are punched. For this reason a hooked nail called a "dog" is preferred. One of these is driven on each side of the rail. Here a point must be noticed; the hook on the dog is at right angles to the other part, while the base of the rail is sloping. As a result, the dog must not be driven vertically downwards, but on a slope (*a*, Fig. 195), in order to obtain as large a bearing surface as possible between the hook of the dog and the base of the rail.

The objection to dogs is, that they do not prevent the rail moving longitudinally like a nail does when put through a punched hole. The difficulty is completely overcome by cutting a small notch out of the base of the rail where the sleepers are to be fixed, and to prevent these being opposite each other and weakening the rail, those on one side of the base lead those on the other side, from 1 in. to 1½ in. (Fig. 196). The notch is not more than a ¼ in. deep, and is taken out of the thin edge of the base, instead of through the thickest part, as is done when holes are punched for nails.

FIG. 195.

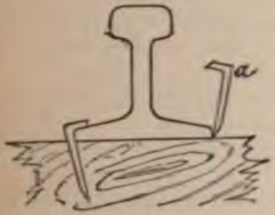
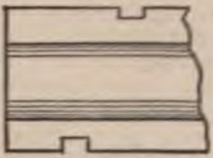


FIG. 196.



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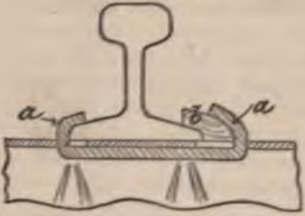
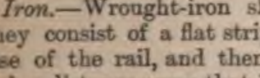


FIG. 197.

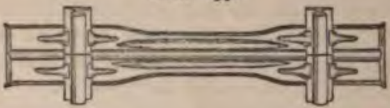


Iron.—Wrought-iron sleepers have been largely employed. They consist of a flat strip bent round at each end, to grasp the base of the rail, and then a block (*a*, Fig. 197) is riveted on at such a distance away that it clutches the other side of the rail.

Steel.—Of late years the use of light steel sleepers has become general. In one form, Colquhoun's patent, the rails are fastened by punching two holes in the sleeper, one on each side of the base of the rail. A steel clasp, or chair, is passed through these holes; the inner end firmly grasps the base of the rail (*a*, Fig. 198), and the whole is secured in position by a wooden key, *b*. The sleepers weigh about 14 lbs. each, and as they are not very thick, are made of corrugated steel to give extra strength. Owing to the narrowness of the clasp, joints cannot be made on the sleepers, and fish-plates have to be employed.

Bagnall's sleeper is made extra wide, and rail joints may be made on it. A central concave corrugation passes from end to end, and, although the sleeper is narrowed in the middle to reduce weight, room is found for two convex corrugations, one on each side of the central concave corrugation (Fig. 199). The jaws, or chairs, four in number, thrown up for the purpose of securing the rails, are strengthened by corrugations at the back; the sides and end of the sleeper are turned down, thereby preventing lateral displacement, especially on curved lines.

FIG. 199.



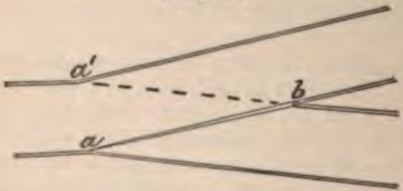
In Hipkins's sleeper, the edges are also turned down all the way round, but the top is flat. Instead of providing four small chairs at each end, only two are thrown up, but they are large ones, and each is strengthened by corrugations.

The author has employed both Bagnall's and Hipkins's, with satisfactory results. Being made of steel, they are very light, weighing only about 12 lbs., and are cheaper and stronger than wrought-iron ones.

Switches.—At junctions of roads, switches or turn-outs have to be employed. For permanent situations these are best constructed by the blacksmith and platelayer, copying those adopted on railways, employing guard or check rails on all curved portions (see Figs. 254–256).

In the working places, and for temporary purposes, where turn-outs are moved from time to time, a more rough and ready arrangement is required. An ordinary form consists of a movable rail about 6 ft. long (*a b*, Fig. 200) pivoted on the centre, *b*. This rail can either occupy the position, *a b*, or that shown by the dotted line, *a′ b*. Where the curve is not a sharp one this device acts admirably, but in quick turns it is not so successful, as it throws a certain length of straight rail where there should be a curve.

FIG. 200.

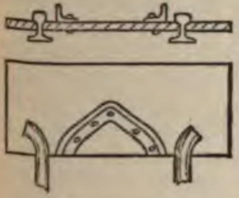


The more general practice is to employ castings for a portion of the switches. Middle beds and wing pieces can be bought of any radius and to any gauge. This construction is very handy, easily laid and removed, and generally applicable under any conditions.

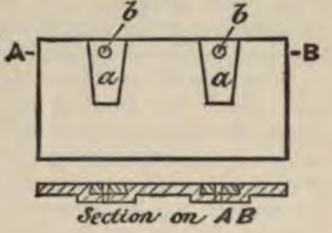
Plates.—To readily turn tubs about at junctions where the space is limited, the rails are made to terminate, and a plate of wrought or cast-iron about 3 or 4 ft. square placed in the gap. The tub can readily be turned about in any direction, but to guide it into its proper way, with a minimum of trouble, an angle-iron guard is usually secured to the plate by means of set pins, and the rails leading from it are opened out for a short distance (Figs. 201 and 202).

The continual passage of the flange of the wheel over one spot on these plates gradually wears a groove in them, especially where there is a lot of traffic, as at pit bottoms, where they are usually employed. To remove an entire plate takes considerable time, and when removed, the iron is good for nothing but scrap. To obviate this, loose wearing pieces should be introduced. These consist of two wedge-shaped plates (*a a*, Figs. 203 and 204), level with the top of the plate, which is recessed to receive them. The sides of the recess are inclined towards each other, so that the wearing pieces are in a manner dove-tailed, and when slid into position in the front end, are secured there by nails, *b b*, passing through them and the main plate. When worn out they can be replaced in two minutes.

FIGS. 201 AND 202.



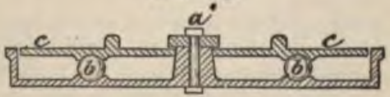
FIGS. 203 AND 204.



Turn Tables.—As the labour of turning a tub on plates is considerable owing to the friction, revolving tables are substituted. These consist of a circular frame and top plate, which, in its commonest form, runs on four wheel rollers.

The movement with the above is comparatively easy, but has been rendered still more so by the employment of ball bearings. In Hudson's turn-table, a series of balls, about 3 in. diam., are arranged in an annular groove (*b*, Fig. 205) and on this the top plate, *c*, rests, being pivoted on a pin, *a*, in the centre. A very simple automatic catch locks the table in any desired

FIG. 205.



position. At Lye Cross Pit, South Staffordshire, the line of rails riveted on the table top are packed up 1½ in. at the end to receive the waggons, and a stop is attached to prevent the tubs running over it, but so arranged that by slight pressure on a foot lever the waggons are released. A standpost and lever are also attached to the outer edge of the table, the lever being arranged to work the catch and also to pull the table round. The advantages are, ease of turning, the automatic catch, and the fact that no lubrication is required; unless turntables of the ordinary wheel roller type are well greased, the labour of turning the tubs on them is considerable.

TUBS.—The general English practice is to make the body rectangular, and construct it either of wood, wrought-iron, or steel. This body rests on a framework, generally of wood—almost invariably oak—or sometimes of iron. To this frame are attached the pedestals forming the bearings for the axles of the wheels.

Bodies.—If wood is employed in the body it may be elm, larch or poplar. The latter is the cheapest and considered most economical, but elm seems preferable, as its wearing capacity is great. The advantages of wooden tubs are their low first cost and the ease with which small repairs are made; their disadvantage is the large amount of repairs necessary. They are usually constructed by cutting the side and end boards to the required lengths, putting an angle-piece of sheet-iron at each corner, and bolting the boards to it. The bolts should have half-round heads placed on the outside of the tub, with the nuts inside.

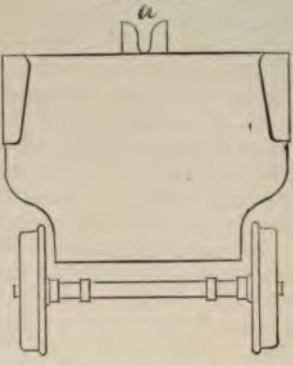
Wrought-iron and steel bodies are largely employed; with the latter metal the weight is less, but corrosion is far more rapid than with wrought-iron. With rectangular tubs the body is generally made of three plates, two forming the sides and ends and the other the bottom. The latter should always be made slightly thicker than the former, as it has to stand the continual blows given by material thrown into the tub. The connection between the bottom and sides is made with angle-iron, which should have unequal sides, say 3 in. by 2 in., the longer side being placed vertically. By doing so, corrosion is prevented at the point where the angle-iron ends. A small quantity of fine coal collects in the corners, gets wet and rots the plate. If the angle-iron is made so high that this small accumulation does not reach above it the action is stopped.

A band of flat strip steel runs round the top of the body, and the joint should always be made at one of the ends, never at the sides. Rivets sometimes come out, and the end of the band projects. If the joint be made at the side, serious injury may be caused to horses through the projecting part catching them. For the same reason, rivets should have snap heads placed outside, and be knocked down on the inside.

The usual form of tub employed on the Continent is shown in

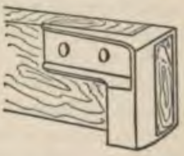
Fig. 206. The advantage of this special shape, is that the carrying capacity is increased without increasing the *height*, for, by bending in the sides at the bottom, practically a distance equal to half the diameter of the wheels is added to the body of the tub, and yet the total height above the rails remains the same. With the Continental thin seams this is important, although, of course, the cost of manufacture must be considerably more than an ordinary rectangular-bodied tub. With this construction equilibrium is very stable, as the centre of gravity is low. They are made entirely of steel, the only wood employed being the buffers, which are situated at each end, and run right across the plate. In general, seven plates are used in the manufacture, two on each side, one at each end, and one in the bottom. The side plates are riveted together, and the end plates secured to the side and bottom ones by angle steel. The frames or feet are channel steel (the pedestals lying in the grooves), and are bolted to the bottom plate.

FIG. 206.



Frames.—The body rests on a frame, either of wood or iron. The former consists of two longitudinal pieces running the entire length, and either connected by two cross baulks, or by two iron strips. These bearers project past the body and form buffers, which should be lined up with the object of preventing those on two successive tubs getting interlocked when passing round curves, as, if they do, derailment inevitably ensues. The buffer end is generally widened out by adding on the inside two pieces of wood and placing a wrought-iron hoop around, but the better practice is to employ a cast-steel or malleable cast-iron shoe (Fig. 207).

FIG. 207.



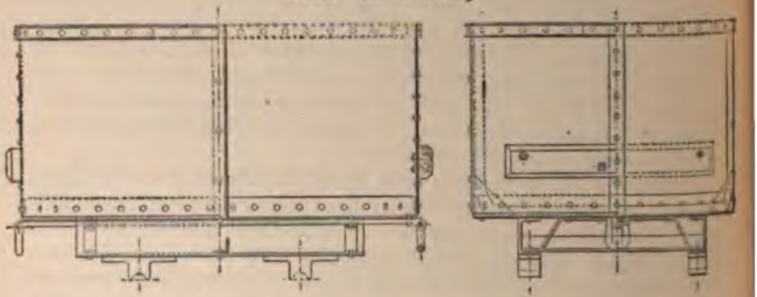
A still better plan is to use iron frames; they cost a little more, but wear better, and are a little lighter. Here the buffers are formed by a strip of wood running across the end of the tub, and cross-buffering never occurs. Figs. 208 and 209 show a tub body and iron framework employed at Bell End Pit, South Staffordshire.

Height.—The height of a tub is governed by the thickness of a seam, but they should not be too deep, or the breakage of coal is great. In low seams, if the tub be decreased in height and the space between it and the roof increased, there is neither the incentive nor the necessity to break the coals to get them into the tub. To remove the necessity altogether, one end of the tub is frequently made hinged, or loose, when the coal does not have to be lifted over the top at all.

Size.—The only advantage of large tubs (carrying 20 to 30 cwt.) is that the useful weight (load) is large compared with the weight of the tub. The disadvantages are, they are awkward to move about, requiring large horses to haul them, and when derailed, several men are required to get them on again. The latter objection can be removed to a certain extent by the employment of small hydraulic lifting jacks, which can be readily carried about. The best size, perhaps, is one carrying from 12 to 14 cwt.; they are easy to handle, capable of being put on the rails by one man, and with any ordinary gradient can be moved by a pony.

Wheels and Axles.—Wheels may be constructed of cast-iron, cast-steel, or forged steel, the former being rarely employed.* Their size should be as large as possible, with a view of reducing friction. The height of the roadways governs the diameter of the wheel where rectangular-bodied tubs are used, but by adopting the Continental form already referred to, a large wheel can be employed in a thin seam.

FIGS. 208 AND 209.



An improvement of considerable value has been the introduction of Eyre's solid forged steel wheels, which are perfectly weldless, bosses, body, and rim, being forged out of a single steel bloom. For the same strength as cast-steel wheels they can be made much lighter, may be either fast or loose on the axle, wear very well, and are practically *unbreakable.*

At the present time, axles are made of ordinary round bar steel, which is rolled to such perfection that it requires no turning. While the diameter should be as small as possible to reduce friction, strength is of far more importance. Weak axles are a constant source of loss.

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* This remark applies to ordinary castings. *Chilled* cast-iron wheels are used at many collieries with marked success.

Two entirely different methods are used for connecting wheels and axles. In one case, the wheels are loose and turn freely on the axle, in the other, they are firmly fixed on the axle, and both are forced to revolve in the same direction with the same velocity. The loose wheel and axle are employed on vehicles travelling on ordinary roads, which are very uneven and where motion takes place in anything but straight lines, and as the roads in older collieries nearly approximated to these conditions, loose wheels were at one time largely employed on underground railways. Their advantage, and the only one they possess, is the small resistance they offer in passing round curves. Naturally a wheel on the outside rail passes over more ground than one on the inside, and if both wheels have to travel at the same velocity, a grinding action between them and the rails must be set up.

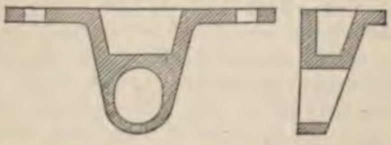
At the present time, colliery roads more nearly approximate to surface railways, and as a result, wheels fast on the axles are becoming more and more employed. On the straight, there is less friction than with loose wheels. Their great advantage is their absolute trueness of gauge. Loose wheels are kept on the axles by cotters, and washers have to be placed against these to prevent excessive wear. No matter how carefully they are looked after the gauge is scarcely ever correct, and the cost of repairs to loose wheels, if cotters and washers are included, is much greater than with fast wheels.

Drawbars.—Tubs are connected together through drawbars, which are preferably riveted to the bottom of the tub. Indeed, the connection between iron and iron should always, wherever possible, be made by rivets; if bolts are used, sooner or later they work loose. In the construction of tubs, two points should be observed: strong drawbars and strong axles. Nothing is gained by making either too weak, and one breakage will minimise all the gain resulting from the decreased first cost.

Where tubs run in sets, drawbars, similar to those used on railway waggons, are employed; the coupling chains are always attached, and ready connection can be made. With some haulage clips, links on drawbars cannot be used; in such cases, a piece of flat steel is used with a hole through each end.

Pedestals—Two types are employed, one for loose wheels, the other for fast ones. The general design of the former is shown in Figs. 210 and 211. With fast wheels, as the axle cannot be threaded through a hole in the pedestal, the bottom part of the casting is omitted, and a wrought-iron guard-strap passed around. To allow of automatic lubrication this strap is bent on one side and leaves the under part of the axle exposed (Fig. 212).

FIGS. 210 AND 211.



To reduce weight, the pedestals are best made of steel, and, as will be noticed, are cored out wherever possible.

Lubrication.—A great deal depends on efficient lubrication, which with loose wheels is nearly impossible, except at great cost. With them, the tub has to be turned over and liquid oil poured into the bearings. This not only means considerable labour cost, but the waste of oil is great.

In some cases, the tubs are run over a pit full of oil, and in doing so depress a piston, which shoots up a jet of oil on to each bearing. All the waste drops back again.

Numerous forms of self-oiling wheels and pedestals have been designed, the majority of which have have been described by Mr. Emerson Bainbridge,[*] but none of them are satisfactory in practice. So long as they are new and are looked after by the officials, good results are obtained, but the rough work of collieries is unsuited to delicate appliances.

FIG. 212.

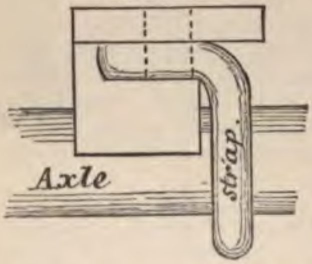
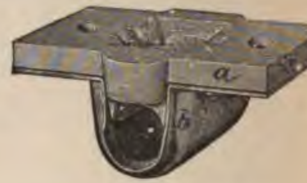


FIG. 213.



A recent improvement of the Hardy Pick Co. shows greater promise. The top part of the pedestal (*a*, Fig. 213) is of the ordinary type, but underneath a steel dish, stamped out of one sheet of metal, is fitted, this keeping the axle in position, and at the same time preventing any dust or dirt getting into the bearing. This steel dish, *b*, is shaped to hold a piece of hair-felt, which is soaked in oil. A considerable number are in use at Nunnery Colliery, and it is stated that one application of lubricant every two or three weeks is sufficient, while a fresh piece of felt is required about every five weeks.

For wheels fast on the axles, by far the greater number of lubricators consist of revolving brushes, or star discs, which supply a small quantity of oil to the bearing as the tubs pass by. Brushes soon wear out, and for such reason the latter arrangement is preferable. Two wheels, one for each bearing, are placed in a semicircular trough, and are generally arranged both to revolve and travel forward a short distance. They are seated on springs, and can thus accommodate themselves to varying heights of the axle.

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[*] N. E. I. xxv. 215 : xxvii. 8.

The advantage of this class of greasers is that they can be put down anywhere, and are quite automatic. In a long haulage plane, they can be placed at intervals where necessary, and considerably reduce both the power required and the cost of lubrication.

In the paper before referred to, Mr. Bainbridge states that the cost of greasing tubs at eighteen different collieries, varied from 0.075 to 0.821*d.* per ton raised. Oil gave the worst results, no doubt owing to the quantity of waste. With grease and corrugated wheels, the cost varied from 0.075 to 0.289*d.* per ton. It will be noticed that this result is over one halfpenny less than the maximum, and shows that some efficient method is very desirable. A low cost may, however, mean that the tubs are badly lubricated.

Haulage by Horses.—Even where mechanical haulage is used on main roads, horses have to be employed to bring the produce from the working places. They are connected to the tubs, either through the medium of a pair of shafts, or a tail-chain joined to a stretch-bar, to which two side traces are attached. Each of these systems has its advantages. With downhill gradients a horse cannot hold back the load when connected to it by a chain, and, therefore, to prevent the tub running away and overtaking the horse, the wheels have to be "lockered," which is done by pushing a short bar of iron through the spokes, and preventing the wheels turning. This is very objectionable, especially on undulating gradients, and causes considerable wear and tear. Shafts are dangerous to horses, as they catch the timber and hamper movement, particularly so in narrow and heavily-timbered roads; they also prevent the horse getting out of the way of the moving train of tubs if the weight overpowers the animal. Up hill there is no difference between chains and shafts.

Feeding.—The chief item of cost in horse haulage is that due to feeding, as not only may an excessive charge be incurred, but the condition of the animals may be so reduced as to unfit them for performing the maximum amount of work. The problem is to keep them in the best condition at a minimum cost, which can easily be done by a proper selection and mixing of food. It may be stated that, however concentrated nutritious elements are obtained, small quantities never afford satisfaction, as hunger is not appeased until the stomach is filled, and, therefore, in addition to foods supplying waste of tissue (oats, beans, &c.), some bulkier body has to be given. This is the reason why hay and straw are found in the feed.

Some prefer to give hay in its uncut state, placing it in a rack where the horse may nibble at it as it prefers, whilst others cut it up with straw into the state of chaff and mix it with hard corn.

The latter procedure seems best. Horses going out of the workings into the stable are hungry, and bolt their food. If the manger contains hard corn only, this being small in bulk, is rapidly consumed, passes into the stomach without being properly masticated, and the animal does not obtain the nourishment it should do. Hay is then attacked, and, being in its natural state, has to be pulled from the rack, pieces are dropped on the floor, trampled under foot and lost, thereby occasioning waste. On the other hand, if hay and straw be cut up and mixed with the hard corn, the manger contains an increased bulk; then, if the horse takes its food voraciously, the first pangs of hunger are soon appeased, the remainder is consumed in a leisurely manner, and the full benefits of the nutritious matter are obtained. In addition, waste is minimised with properly constructed mangers.

Regarded from the standpoint of cost compared with benefit, bran is quite out of place as a food. Its chief use is as an appetiser, and for its corrective and laxative properties. Sometimes it is given as a mash at week ends, when a horse has to stand in the stable all the next day, while others mix a small quantity with each feed. As it seems preferable to avoid extremes with such regular bodies as those of colliery horses, the latter course is generally adopted.

Respecting the different varieties and mixtures of hard corn, every one interested in the management of colliery horses should refer to a paper by Mr. C. Hunting,* in which the constituents of various foods are fully described, and the whole question gone into. It was long considered that oats alone were sufficient. Mr. Hunting points out that this is correct to a certain extent, as they contain more proportionate quantities of nutritious elements, but for very hard work, such as underground horses have to do, the consumption of muscle is far in excess of the waste of any other tissue, and food containing a heavy proportion of nitrogenous or flesh-forming material must be given. If the choice were limited to one article, oats are superior, but an equal weight of a proper mixture of beans and maize gives better results than oats alone; better in a double sense, because not only is its flesh-forming capacity greater, but it is considerably cheaper. Peas are often used as a substitute for beans, as they run a little cheaper, but are very heating, and should only be used with care.

Mr. Hunting strongly advocates the use of a mixture of green food during a short time in the summer, but some discretion is required in its administration. Under no circumstances should it be sent down the pit when soaked with rain. It should not be allowed in-bye, where a tired horse may gorge itself when waiting at a siding.

A horse's stomach is relatively small compared with its bulk, so that it cannot retain sufficient food to maintain the animal for long intervals. Mangers should therefore be established at the siding to which the horses travel, so that they can eat small quantities while waiting there.

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* N. E. I. xxxii. 61.

Cost of Feeding.—At a colliery where the horses are on an average 15 hands high and 80 in number, the cost of feeding during the years 1885–1892 has varied from a maximum of 12.25*s.* per horse per week to a minimum of 8.66*s.*, the average for the whole of the time being 10*s.* 2.891*d.* Two samples of feed are given below :—

	Jan., Feb. and March, 1888. Cost per horse per week, 11.44*s.* Lbs. per day.		Jan., Feb. and March, 1890. Cost per horse per week, 9.75*s.* Lbs. per day.	
Beans	2.577	7.135	3.204	7.349
Maize	2.922		2.615	
Oats	1.636		1.530	
Bran	9.398	...	8.239	
Hay	13.762	...	14.499	
Clover	1.426	...	0.549	
Straw	1.767	...	5.759	
Total	33.488 lbs. per day.		36.395 lbs. per day.	

Cost and Life of Horses.—Figures relating to the purchase of horses at the same colliery for a period of thirteen years give the average cost of each one as £21 4*s.* The average life for the same period practically amounts to about eight years, but the percentage of deaths from accidents to horses employed being rather large—6.198—during the last six years, the life may better be taken at nine years, which is the figure given by Mr. Hunting in the paper already referred to, where the life of horses, on an average at twelve collieries, amounted to that length of time. Mr. Hunting gives the average number of deaths in each year for twenty-one years: horses, 4.70; ponies, 3.08 per cent.

Cost of Corn Cutting and Ostlers.—At the colliery under notice, the feeds are all prepared and mixed at bank by two men, and the cost per horse per week equals 5.296*d.* Two men are employed cleaning and attending the horses down the pit, both on the day and night shifts, and during the daytime one of the men goes round the different parts of the pit and sees that the horses are supplied with corn and water, while the other cleans out stables, &c. The cost per horse per week is 1*s.* 9.513*d.*

Shoeing.—With pit horses rough shoeing is done, old scrap iron being used up in many cases, but against this has to be set the trouble and time the blacksmith is put to in going into the workings, often a considerable distance, when a horse casts a shoe. The average charge may be taken as 6*d.* per horse per week.

In two most interesting papers by Mr. J. A. Longden* the following directions are given: Never pare the sole or frog, and only cut enough of the horn off at the lower end of the hoof to allow the shoe to bed properly; above all, reduce the weight of the shoe to the lowest possible point, and do not employ "calkins" on either heels or toes. Three nails on the outside and two on the inside are quite enough for the fore-feet, and they should never be placed near the heels. He gives the cost of shoeing ponies at Clay Cross and Blackwell Collieries, Derbyshire, at 3.23d. per horse per week.

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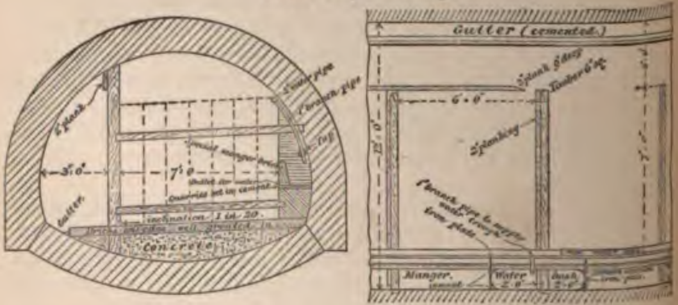
* *Shoeing of Pit Horses*, Brit. Soc. Min. Stud. iv. 104; Ches. Inst. ix. 273.

Taking the average of many years, the total cost incurred for each horse per week is as follows:

	s.	d.
Keep	10	2.891
Repairs to harness	0	2.538
Cutting and preparing feed	0	5.296
Ostlers	1	9.153
Brushes and currycombs	0	0.228
Veterinary surgeon and medicine	0	3.058
Shoeing	0	6.000
	13	5.164

Arrangement of Stables.—Pure water and plenty of ventilation are essential. The stables at Lye Cross Pit are shown in Figs. 214 and 215. Each horse has a stall 7 ft. long by 6 ft. wide, and a corn manger made with specially shaped bricks, 4 ft. long. A water bosh is placed between each two stalls, and a 2 in. main-pipe with down branch pipes delivers water to each bosh, which has a hole and plug in the bottom to allow of easy emptying.

FIGS. 214 AND 215.

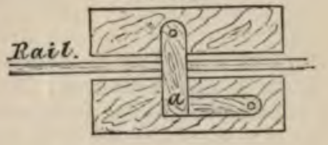


The stables at Eppleton Pit are most elaborate. Each pony stands in a distinct arch, 5 ft. 6 in. wide by 6 ft. long, the brick-work between each stall being 18 in. thick. A passage is provided behind the mangers with communications to each stall, through which the horse's food is introduced, thereby not only facilitating that of the empty one. The working capacity of such an arrangement is one-half that of a road laid with a double line of rails. For inclines where intermediate landings are worked, this arrangement gives excellent results, and in many cases, under such conditions, as much mineral can be jigged down with this system as by any other.

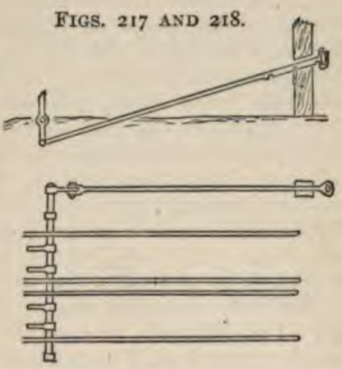
In stall roads going into the working place, the common practice in steep mines is to make a full set going down one road haul up the empty set in the next adjoining roadway. Where the inclination is great (above 35°) the tubs have to be placed on special carriages to throw the coal into a horizontal position. If this were not done the load would be emptied as it passed down the incline.

Blocks or Stops.—Arrangements are always made at the top of inclines to prevent the tubs prematurely running down before the set is made up. The common form of blocks is shown in Fig. 216, but where the inclination is steep, the top part, *a*, is stretched across the whole width of the rails, and the two wheels of the tub rest against it. If the sets are always jigged on the same side a balance block can be used (see Fig. 237). Mr. A. R. Sawyer* describes a good block arrangement which is opened and shut by hand at a distance, the working of which will be easily understood from Figs. 217 and 218.

FIG. 216.



FIGS. 217 AND 218.



Drums and Pulleys. — In permanent situations, and on long inclines, drums similar to those on winding engines are fastened on a shaft, the empty rope coiling on one and the full rope on the other. A brake has to be provided to retard the descent, and to keep the velocity from getting too great. These drums occupy a considerable amount of room, and in confined situations pulleys become necessary. These may either be fixed on a vertical or horizontal axis, and may be made for working with a chain or rope. Chains are very convenient; they can be easily added to, if the plane lengthens, or are shortened with equal ease. They can also be transported much easier than wire ropes, but they are heavier, more liable to breakage, and require a steeper inclination, owing to the greater friction. If ropes are employed either a clip, or a **C** pulley with several coils on it (see p. 207) may be used, while for chains, the throat of the pulley may either be fitted with **Y** grips or feet, and in the latter case several turns are passed round it. For short inclines, with only one or two tubs jigged at a time, small hand jig-wheels are employed (Fig. 219), which can be readily moved about from place to place, and are usually secured to a prop.

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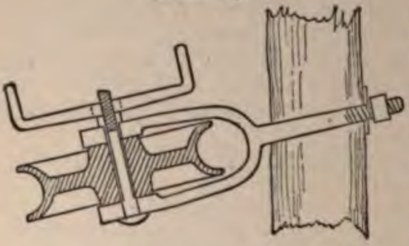
* *Miscellaneous Accidents in Mines*, 1889, p. 153.

FIG. 219.



Brakes.—All-round ones are preferable on small wheels, the brake-ring being of cast-iron, and the strap of wrought-iron. Some material, such as a wooden curb, should be placed between; in the smaller wheels, a lining of hemp rope, attached to the brake-strap by bolts, gives excellent results, but care should be taken to counter-sink all the pin-heads.

Mr. Malissard Taza describes an ingenious fan-brake on a self-acting incline plane at Bilbao,* which consists of four radial blades, about 6½ ft. wide by 16½ ft. diam., two band-brakes being also provided for safety. The fan-brake works slowly at first as the tubs move away, gradually increasing in speed until the journey attains the rate of 10 ft. per sec., after which motion is uniform, owing to the resistance of the air. The advantages are: absence of continuous friction of brake-strap, with wear and tear, uniform velocity, speed capable of any regulation and variation by addition to, or removal from, the arms of the fan, and less attention while the journey is running, none being required except on the arrival of the waggons at the top of the incline.

Rollers.—In every system of haulage small rollers should be placed at intervals, to keep the ropes and chains from dragging on the ground, as, if they do, not only is the resistance to be overcome much greater, but wear is rapid. The rollers employed are small cylinders on a spindle, and may be either constructed of cast-iron, steel, or wood. Cast-iron ones possess no advantages, and rapidly wear out. For surface and exposed situations, wood is not to be recommended, as it cracks and splits under climatic influences. Underground, the same objection does not hold good, and wood is often employed, it being contended that it is better that the rope should wear the roller than the roller wear the rope; the latter may happen if steel of a hard nature is employed.

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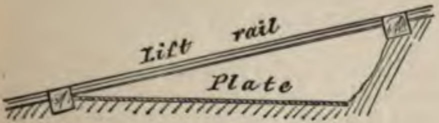
* Soc. Ind. Min. (2^e Série), xiv. 1065.

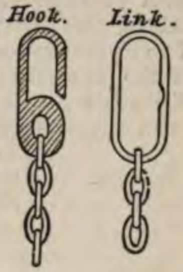
Junctions.—In steep mines, where intermediate hanging-on places are worked, the continuity of the rails has to be interrupted at such places. The branch roads pass away level, or nearly so, and at the joining place an iron plate is laid, which is bridged over by rails that can be lifted in and out of position (Fig. 220).

The alteration in length of the jigging-rope is either obtained by adding on a piece of chain provided with large links opposite each intermediate landing,* or by employing a number of short pieces of chain, which lie at the side of the jig when not in use. Each length is provided with one piece, which can be joined either by shackle connection or by a specially shaped pair of links † (Figs. 221 and 222).

FIG. 220.



FIGS. 221 AND 222.



Transmission of Power.—One of the first questions to be considered in mechanical haulage is that of the position of the engines.

(1st) They may be placed underground, and the steam generated there also.

The objections to placing boilers underground are the great danger of the fires igniting fire-damp, or the coal in proximity to the boilers or flues, and the insecure foundation afforded by the general run of strata.

(2nd) The engines may be placed underground, and steam generated at the surface and conveyed down the shaft to them.

This practice has, in some few instances, caused fires, by the small coal which accumulates on the pipes becoming so heated as to burst into flame. A loss, which increases with the depth and the presence of water in the shaft, results by the radiation of heat from the steam-pipes, however well they may be coated with non-conducting composition. In some instances the loss may reach from 8 lbs. to 15 lbs. of steam pressure, while better results show not more than 4 lbs. or 5 lbs. Putting aside the inconvenience of using steam, if it can be cheaply generated—as, fo instance, by the waste heat from coke ovens—a good performanc of useful effect is given.

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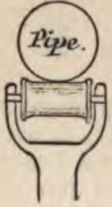
* *Miscellaneous Accidents in Mines*, A. R. Sawyer, 1889, p. 162.

† Min. Inst. Scot. ii. 122.

At Broomhill Colliery, Northumberland,* steam is conveye to a pump 1414 yds. from the boilers at bank. All pipes ar coated with a non-conducting composition; the loss by condensation is 21.06 per cent. The pressure at the pump is 13 lbs. below that in the boiler at bank.

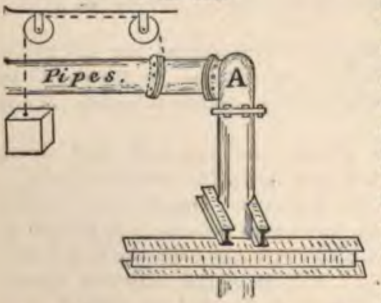
Mr. Baure † states that experiments at Bézenet Colliery, France, with an engine situated underground, 1200 ft. away from the boilers, with pipes about $3\frac{1}{4}$ in. diam., showed a loss of $18\frac{1}{2}$ per cent. Two receivers were placed in the length of pipes, one at the top of the pit (206 ft. from the engine), and the other at a further distance of 984 ft.

FIG. 223.



In carrying steam large distances, the pipes should be covered with a non-conducting composition, and rest on supports fitted with a roller (Fig. 223), so that they can move easily to and fro. Stuffing-box expansion joints should be used throughout, at intervals of from 40 to 50 yds. The secret of the success of transmission, seems to be due to providing two fixed points in each length of pipe, and forcing expansion to take place equally in both directions. In horizontal lengths, the pipes are clamped half-way between two expansion joints, but where they are on an incline, the fixed points are placed nearer the lower end. In addition, steam should never be turned out of the pipes. With these precautions little difficulty is experienced from expansion, but the greatest nuisance is in getting rid of the condensed water, for although steam traps, or separators, may be placed in the range, they only *collect* water out of the pipes, and it has to be still discharged into the roadways. The recent invention of what is called the "steam loop" promises to entirely remove the above complaint.

FIG. 224.



At Elemore Colliery, Durham, where the length of the column is 224 yds., expansion joints are entirely dispensed with in the shaft. The arrangement at the surface is shown in perspective in Fig. 224, the part marked A being a knuckle-piece, the pipe going through two right angle bends. The dotted line represents a chain passing over wheels, holding a block of metal weighing about 10 cwt., which checks the too sudden fall of the pipes in the shaft during contraction. The horizontal length of pipes in the drift is 40 ft., calculated to allow for a movement or spring of from 11 to 12 in., which is the greatest amount of expansion when carrying steam. At every third pipe (each 9 ft. long) in the shaft, support girders are fixed below the flange to allow one foot of slide. If it were not for these, the pipe column would bulge on expansion. The column of pipes is free to move in a vertical direction, and the whole weight is supported by a pair of larger girders fixed at the Main seam level. The advantages of the arrangement are, that expansion joints are completely done away with, and the trouble attending them, as, for instance, the leakage of steam, which seriously affects the roof and sides of the mine. This is most noticeable at the beginning of the week, when steam is being got up, and when, owing to contraction, steam finds vent at the expansion joints (where such are in use) until the column is thoroughly heated again.

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* N.E.I. xxxv. 159; xxxvi. 13. † Soc. Ind. Min. (2ᵉ Série), xiv. 297.

(3rd) The haulage engine may be placed on the surface, and the ropes carried down the shaft.

This is the practice most in favour, and is unquestionably the best. With any method of haulage, where the rope travels at high speeds, and is continuous from the engines to the end of the plane, perhaps the advantages are not so apparent. Ropes working in the roadways of mines are apt to get injured, and are more liable to break in the shaft and cause damage; but with any of the slow speed endless rope systems, where the shaft rope is only used to transmit power from the surface to a series of pulleys situated near the pit bottom, and is not liable to injury or breakage, most satisfactory results are obtained. It adds the wear and tear of another rope to the expense, but such a rope can be placed in position in a very short length of time, compared with that necessary to fix pipes, either for steam or compressed air. The cost of excavation for engine-houses underground is always more than on the surface, as the men work shorter hours and get more money.

Transmission of power with wire ropes for very long distances or circuitous routes is not to be recommended, the useful effect being small, and the wear and tear considerable.

Compressed Air.—Transmitting power by compressed air has already been described. The great advantage of employing this agent is that a certain quantity of pure air is delivered into the mine, which is practically of no benefit whatever, if it be done at or near the pit bottom, where main haulage engines are generally placed. In cases, however, where engines have to be worked at considerable distances away from the pit bottom, this method is very advantageous.

Electricity.—This subject has also been considered. Its employment offers advantages for quick speed haulage at points a long distance away from the shaft. The convenience and ease with which it can be applied are its chief recommendations. It is not too much to say that a man could lay a greater length of electrical mains in one day than he could pipes in a week. In non-fiery mines, no possible objection can be brought against this system, and by employing every safeguard possible, its use should not lead to danger in any way.

Different Systems of Haulage.—Having decided on the position of the engines, the different systems of haulage that are in use may now be considered. These may be divided into four heads:

(*a*) *Direct Haulage*, where the gradient of the road is sufficient to allow the empty tubs to run into the workings and to draw with them the haulage rope.

(*b*) *Tail-rope System*, where a second, or tail-rope, of lighter make has to be used to haul the empty tubs and the main rope into the workings, the gradient not being sufficient.

(*c*) *Endless Chain System*, where an endless chain passes from the engines along one side of the road, round a pulley at the far end, and back again on the other side of the road to the haulage engines; the empty tubs are attached to one-half of the chain, and the full ones to the other; the former proceed towards the workings, and the latter towards the shaft.

(*d*) *Endless Rope System*, the difference between this and the one last named is that a rope is employed instead of a chain.

DIRECT ACTING HAULAGE.—This system is employed for hauling out of workings to the deep of the pit bottom. It requires a single line of rails, and a gradient against the load sufficient to allow the empty tubs to run back themselves, to carry with them the rope, and to overcome the friction of the drum. As with other machinery, the engines should consist of a pair. Only one drum is required, which should be capable of being thrown out of gear and of running loose on the return journey.

Size of Engines Required.—The number of tubs in a loaded train, or "set," is regulated by the size of the engines and by the pressure of the steam; the size of the engines depends on the quantity of coal which has to be hauled each day.

To illustrate the method of calculating the size of engines required, it will be best to assume some case. Resistance to traction is due to three causes—(1) Friction of axles on pedestals and wheels on rails, proportional to weight; (2) Imperfections of road-laying—*i.e.*, bad joints and crooked ways, proportional to weight and square of velocity; (3) Resistance offered by air currents.

The former has by far the largest effect. With a well-lubricated turned axle and large-sized wheel rolling on a smooth rail, friction is small, but colliery tub axles are generally rough, unturned ones, and can seldom be kept perfectly lubricated; it, therefore, is generally considered that an allowance of $\frac{1}{30}$th of the weight should be made for friction.

Let it be assumed that 75 tons an hour have to be hauled up an incline 1500 yds. long, having an average inclination of 1 in 20; that the tubs weigh 6 cwt. each, and carry 12 cwt. of coal; that the pressure of steam at the engines is 65 lbs.; and that the average speed of the set is 8 miles an hour.

Eight miles = 14080 yards, so that the speed per min. $=\frac{14080}{60}$ $= 234.6$, and each journey takes $\frac{1500}{234.6}=6.4$, say, 7 minutes, to travel one way. The time in and out will, therefore, be 14 minutes, and allowing 3 minutes at each end for changing makes 20 minutes. Three journeys per hour should thus be got out; but there are always delays, and it will be best to rely on, say, $2\frac{1}{2}$.

As 75 tons per hour have to be delivered, each set contains $\frac{75}{2.5}$ $= 30$ tons of coal, and as each tub holds 12 cwt. there will be 50 tubs in each journey. Fifty tubs weighing 6 cwt. each $= 15$ tons, therefore the gross load is $30 + 15 = 45$ tons; but as the inclination is 1 in 20, the net load will be $\frac{45}{20}=2.25$ tons $=5040$ lbs.

For this, a plough steel rope $2\frac{5}{8}$ in. circumference, weighing $7\frac{1}{4}$ lbs. per fathom, will be sufficient, and its total weight will be $750 \times 7\frac{1}{4}=5437.5$, say, 5440 lbs. The net load on the engine will be $\frac{5440}{20}=277$ lbs.

As the gross weight of the set is 45 tons, the resistance due to friction (taking this @ $\frac{1}{30}$th) $=\frac{45}{30}=1.5$ tons, or 3360 lbs.; for the rope, frictional resistance is $\frac{5440}{30}=182$ lbs.

The total load on the engine is, therefore:

$$\left.\begin{array}{lr}\text{Due to set} \quad . \quad . \quad . \quad . & 5040 \\ \text{,,} \quad \text{rope} \quad . \quad . \quad . \quad . & 277 \\ \text{Friction of set} \quad . \quad . \quad . & 3360 \\ \text{,,} \quad \text{,, rope} \quad . \quad . \quad . & 182\end{array}\right\} = 8859 \text{ lbs.}$$

If it be decided to have a drum 6 ft. diam. and a pair of engines having a stroke of 3 ft., as the pressure of steam is 65 lbs. the size of the engines can be found by the rule:

Area of cylinder (a) × pressure × twice the length of stroke = load × circumference of drum.

In this case:

$$a=\frac{6\times 3.1416\times 8859}{65\times 2\times 3}=428.18,$$

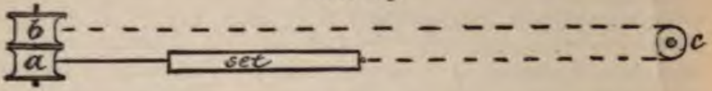
which is the theoretical area of the two cylinders; to overcome internal resistance and friction of engine 35 % of this amount should be added—*i.e.*, 147.83, so that the area of the two cylinders becomes 578.01, or each of them = 289 sq. inches.

The diam. is, therefore: $\sqrt{\frac{289}{.7854}}$, practically $19\frac{1}{4}$ inches; or, to avoid being under power, say, a pair of 20 in. cyl. by 3 ft. stroke.

The quantity of material a pair of engines of given dimensions will haul in a certain time can be easily determined by applying the converse reasoning to the foregoing.

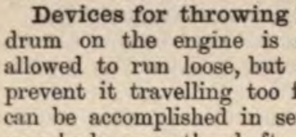
MAIN AND TAIL-ROPE HAULAGE.—In this method, a lighter rope, called a tail-rope, has to be employed to haul back the empty set from the shaft to the workings, such addition being caused either by the gradient being undulating, or not sufficient to allow the tubs to run back of themselves. Fig. 225 illustrates the theory of the system. Two drums are employed; on one *a*, the main rope is coiled, and the other, *b*, contains the tail rope, which passes from it to the extreme end of the plane round a pulley, *c*, and is finally attached at the back of the set. As this rope only has to haul the empty tubs back again, its size is much less than the main rope, but it has to be twice as long.

FIG. 225.



Devices for throwing Drums In and Out of Gear.—Each drum on the engine is alternately thrown out of gear and allowed to run loose, but should be provided with a brake to prevent it travelling too fast and paying out slack rope. This can be accomplished in several different ways; either the drum may be loose on the shaft and driven by clutches, or fixed to the shaft and a sliding-carriage employed, throwing them in and out of gear. If clutches are employed, they may be the same as those used for, and described under, endless-rope haulage. With drums running loose, and travelling at high speeds, wear is considerable, and they should be bushed with some metal, such as brass, which allows them to turn with little friction, and is capable of renewal. Allowance for wear should also be provided on the shaft, which has to be nicely turned. This arrangement possesses an advantage, inasmuch as both drums can be placed on the same shaft, while with a sliding carriage they must be on separate ones.

FIG. 226.



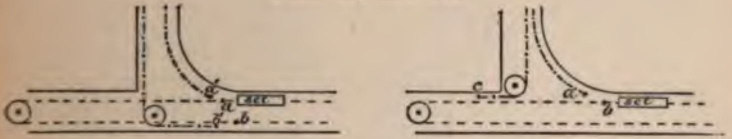
Sliding carriages are generally moved by an arrangement of levers, but even with compound levers a considerable amount of force is required. At Elemore Pit, the sliding carriages (Fig. 226) are moved by an endless screw gearing into a cog-wheel, on the same shaft of which is keyed an eccentric, with its link going to the carriage. As the screw is turned, the cog-wheel and shaft revolve; consequently, the eccentric draws its link forward, and pulls the sliding carriage out of gear.

Methods of Working Branches.—In branch, or subordinate roads, a return pulley is necessary at the far end, and a separate length of rope is required for such, both ends of which reach to the junction with the main road. Joints are provided in the main-road ropes, and the branches are worked by disconnecting portions of the main-road ropes, and attaching the ropes of the branch road to them, connections being made by ordinary sockets and shackles.

Three methods are adopted for changing the ropes under normal conditions; such cases where the rope overhauls itself—that is to say, where it runs in-bye without the aid of engine-power—are matters of detail, and do not affect the main systems. In two of these, the ropes are changed when the set is at the branch; in the other, when it is at the pit shaft.

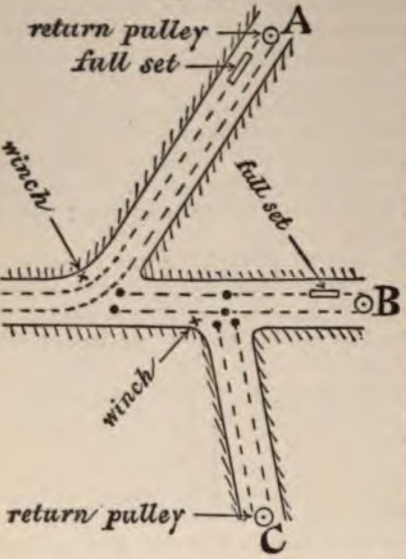
Fig. 227 illustrates one method of changing when the set is near the branch end. A shackle connection is provided in the tail-rope, and so arranged that it arrives opposite the branch at the same time as the set does—that is to say, it ought to do; but here, as in every other method, it is found advisable to have a winch, with a chain and hook fixed at the way-end, to winch up the main rope to meet the branch rope, as it often happens that they do not quite face each other, which is not at all surprising, considering the great length of rope in use. The main road tail-rope is then disconnected at the points *a* and *b*, and the shackles of the branch rope, *a′* and *b′*, attached in their place. As soon as the engine has started again, the empty set leaves the main road and goes into the branch one. A slightly different method is illustrated in Fig. 228, the changing also being made when the set is at the branch. The end *a* replaces *b*, which is then brought on a little further by the engine and connected to *c*. Here the tail-rope always remains entire.

FIGS. 227 AND 228.



In the other method, the ropes are changed when the set is at the shaft. Joints in the main rope are so arranged that when the set is out-bye, all the shackles are opposite the different branches (Fig. 229). Suppose there are three branches, A, B and C, B being ready for an empty set. The full set, which is standing at another branch end, say A, having been hauled to the shaft, A's branch rope is disconnected from the main rope, and B's branch rope connected to it. The engine is then started and the empty set at the shaft hauled in-bye into the branch B without stopping at the branch end. Nothing can be more simple and expeditious than this method. To facilitate matters and save time, if it be desired to bring a set out from C, the ropes can be partially changed while A's set is running.

FIG. 229.



In the latter system, no stop takes place from the start to the completion of the journey, as the ropes are changed at the branch at the same time as they are at the shaft; while in the other two methods, a stop has to be made at the branch end, or in all two stops are required, as the ropes have also to be changed at the shaft. Where time is an object, the advantages of the third method are self-evident.

The rope is automatically disconnected from the set when it reaches the shaft either by a knock-off link (Fig. 230), or preferably by the arrangement shown in Fig. 231. As drawn, the hauling rope which is attached to the short length of chain, *a*, will pull the set along, but at the detaching point at the out-bye or shaft end, a horizontal striking bar, which is stretched across the road, catches the lever, *b*, moves it backwards in the direction shown by the arrow, lifts up the link, *c*, and detaches the set, which runs down an inclined "kip" to the shaft.

FIG. 230.

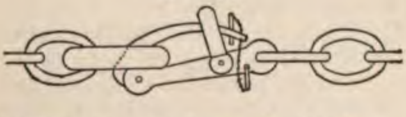
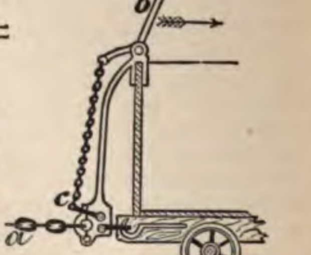


FIG. 231.



ENDLESS CHAIN.—This system differs from the foregoing in the fact that a double line of rails is necessary; that a chain is employed travelling over the top of the tubs, and, as the name implies, is endless; that the speed is small, not more than three miles an hour; and that the tubs are attached singly at equidistant intervals, depending on the quantity required to be hauled.

Attachment of Tubs.—Where the gradient is small, the weight of the chain resting on the tubs is sufficient to drag them along, but for steeper inclinations a **Y**-shaped fork, catching a link of the chain, is firmly riveted to the end of each tub (*a*, Fig. 206).

Driving Pulleys.—For giving motion to the chain, two different forms of pulley are adopted. In one, a series of **Y**-shaped jaws, with the groove at the bottom just wide enough to take the link edgeways, are arranged at intervals around the circumference. The chain only passes half round the pulley, the necessary grip being obtained by the links of the chain catching in the forks.

In this system, as with the endless rope, it is absolutely necessary for efficient working that small guide ("leading-on") pulleys should be arranged just before the chain (rope) reaches the driving wheel, so that it may be accurately led on in the proper place.

FIG. 232.

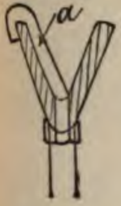
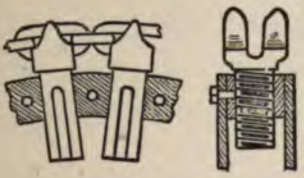
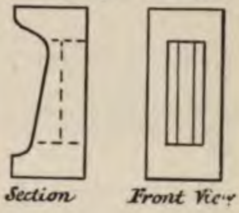


FIG. 233.



FIGS. 234 AND 235.



Instead of fixing forks in the throat of the pulley, a series of pieces of square iron (*a*, Fig. 232) may be placed alternately on opposite sides. This iron is bent back at the top to clip the rim, and at the other end passes through a hole in the throat of the pulley and is secured on the underside by a nut.

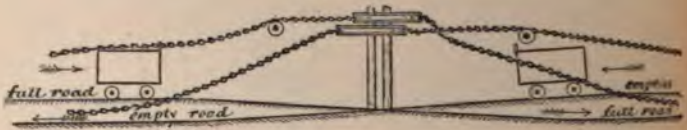
With the ordinary form of fork, no allowance is made for the lengthening of the links of the chain due to wear. When everything is new they are fixed at correct intervals, grip the chain, and prevent any slip. With wear, the links lengthen, and do not properly fit the jaws. This inconvenience has been overcome by an arrangement due to Mr. Briart, which consists of a series of **Y**-shaped grips of steel screwed into the periphery of the pulley (Fig. 233). As the links of the chain lengthen, the grips are unscrewed, so as to increase the distance between each, thus fitting the altered length of the links of the chain.

The better plan appears to be to use a series of blocks of steel, called "feet," arranged at intervals around the circumference of the pulley, and coil the chain two or three times round to get the necessary grip. These feet are of an inverted cone shape in section (Figs. 234 and 235), with the object of preventing the chain from climbing, and, owing to the recess between each, the circumference of that part of the pulley on which the chain works is in plan like a polygon, preventing any possibility of slip. They also take any wear, effecting considerable economy from this source. They are secured to the throat of the pulley by bolts with counter-sunk heads, which may either pass through holes in the feet, or, preferably, through a slit running down the centre, as the latter allows a little adjustment.

Taking up Slack.—It is just as essential with endless chain as with endless rope that means should be provided for automatically taking up the slack produced by lengthening during wear. This is a point often neglected; indeed, the common practice is to allow the chain to extend until it is only kept on the pulley with great difficulty, and then to cut out a piece. Far better results are given by any of the tension arrangements described under endless rope haulage.

Working Branches and Curves.—The chief advantage of the endless chain is the ease and small amount of labour with which branches and curves can be worked. With branches, all that has to be done is to arrange a series of pulleys one above the other on a vertical shaft, each one working a chain. Even with the most regular output, the quantity coming from any branch is seldom the same as that from its neighbour, and hindrances may often occur in any one of them. If all these pulleys are keyed on the upright shaft, the stoppage of one branch means the stoppage of all. To allow any of them to remain idle while the others are working, only one, and that the driving pulley, is keyed on the shaft; the others are loose, and arranged to be thrown in and out of gear by clutches, similar to those used in endless rope haulage.

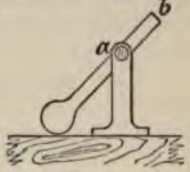
FIG. 236.



When the tubs approach a junction or the delivery end, they are easily detached by arranging a small guide pulley close to the roof, and passing the chain over it (Fig. 236). At this point the chain is lifted out of the fork on the tub, and detached without any manual labour, and if the rails are arranged on a slope, the tub still continues moving under the influence of gravity, passes under the upright pulleys, meets the chain again further on, and automatically re-attaches itself. Curves are worked on the same principle; the tubs detaching and attaching themselves, and gravitating round the curved portion. With an endless rope automatic detachment can be secured, but in only one form of clip can the tubs re-attach themselves.

Means of Minimising Breakages.—Unfortunately breakages are common occurrences with the endless chain. The proverb is quite true "that a chain is not stronger than its weakest link." The result of a breakage on a steep incline may be very disastrous, as the tubs run downhill, sweeping everything before them. To prevent this, it is usual to apply on the loaded road a balance-block arrangement (Fig. 237) pivoted on a point, *a*. In its journey each tub depresses the end, *b*, and passes over the obstruction, but immediately they have gone by the block falls into the position shown, and stops the tubs running back.

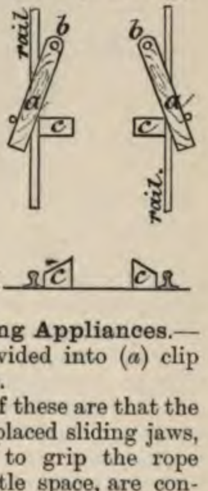
FIG. 237.



Where the inclination is not steep, the arrangement illustrated in Figs. 238 and 239 can be employed. In their normal position two blocks, *a a*, pivoted about pins at *b*, lie across the rails, as shown in plan, but are pushed aside by the wheels of the tubs up a small greased inclined plane, *c*, to descend again immediately the tubs have gone by, and so block the road.

The chain is carried above the surface of the road on the tubs, that is, so long as it is entire; if broken it trails on the ground. If, therefore, a series of **Y**-grips be arranged in the centre of the way, they do not catch the chain so long as it is whole, but directly it breaks they come into action and firmly hold it.

FIGS. 238 AND 239.



ENDLESS ROPE HAULAGE:—**Driving Appliances.**—The methods employed for driving may be divided into (*a*) clip pulleys; (*b*) conical wheels; (*c*) grooved wheels.

(*a*) *Clip Pulleys.*—The general construction of these are that the rope is conducted into a groove, in which are placed sliding jaws, which are pushed downwards, causing them to grip the rope firmly and prevent slipping. They occupy little space, are convenient, side friction is entirely avoided, and as the rope only passes half round the pulley the bending action is not great.

A good form of clip pulley is Barraclough's. One side of the pulley is entirely separate from the other, connection being made by bolts, while any required distance between the two parts can be maintained by set pins, placed at intervals around the circumference. By such means, the pulley can be altered to accommodate any size of rope in a few minutes. All round the circumference are a series of taper pockets opposite each other, inside which work two sliding jaws (*a*, Fig. 240), which are hollowed at the bottom and sides to receive the rope. These jaws are seated on springs, *b*. When the rope enters the pulley, the weight forces the jaws down the taper sides of the throat, and so narrows the distance between the jaws, causing them to grip the rope, while, as soon as the weight is taken off, the springs assist to release and relieve the rope.

A pulley employed in Scotland, both for cable tramways and mine haulage, is that shown in Fig. 241. The ordinary arms of the pulley terminate in a horizontal and vertical flange, *a* and *b*, to which are respectively bolted the taper throat rims, *c* and *d*, a piece of wood, *e*, being interposed between. It is stated that no injury whatever is caused to the rope, and Mr. D. Ferguson[*] gives some figures which seem to bear out that view.

FIG. 240.

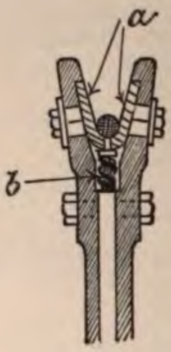
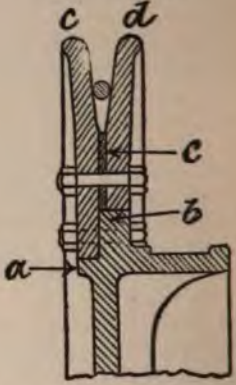


FIG. 241.



It is, however, difficult to see how any clip pulley can work without flattening the rope; their very principle of action is to grip or wedge the rope, and the greater the load, the greater the wedging. There are, of course, good and bad clip pulleys, and probably the latter predominate, at any rate, they are responsible for a great deal of prejudice. At a colliery with which the author is connected, one of the best known forms of clip pulley was originally used for driving rope haulage, but was removed and replaced by a taper C pulley. Considerably more than three times the work is now being obtained from the driving ropes.

To avoid the flattening action, a pulley has been designed having a serpentine groove in the throat, and so long as this remains in the curved state, and does not wear *straight*, fair results are said to be obtained.

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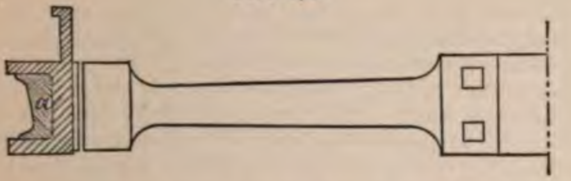
[*] Min. Inst. Scot. vii. 145.

(*b*) *C Pulleys.*—To avoid the flattening of the rope, C pulleys are employed, which originally consisted of a pulley in the shape of a C, around which the rope was coiled several times to give the necessary grip and prevent slipping. Here flattening is certainly avoided, but another disadvantage is introduced in the shape of side friction. On their adoption, it was found that the pulleys wore in rather a peculiar manner; their dished form was soon lost and the diameter of the coming-off side became less than the going-on side. Seeing that the pulley wore in this way, it soon became the practice to construct them so, and now the great majority are made slightly conical, the diameter of the going-on side being larger than the coming-off side.

The throat of the pulley is made parallel (Fig. 242), but loose wearing segments, *a*, are bolted in. These wearing segments save large sums of money. A pulley costs from £15 to £20, while the segments can be obtained for £3. In addition, the segments can be changed in a short time and are easily handled; pulley changing not only requires far longer time, but considerably more men. Another point is that pulleys should always be purchased in halves; in such state they can be transported and got into place with half the expense they otherwise would. Loose wearing segments and pulleys in halves have materially reduced the cost of modern rope-haulage.

FIG. 242.



As to the amount of taper necessary, experience is the only guide, but the heavier the load the greater it must be. If properly proportioned these pulleys work very smoothly; the rope practically does not slip downwards, but follows a serpentine path from the time it goes on at the top until it comes off at the bottom. Side friction is, to a certain extent, avoided, as practically none exists between the successive coils, but where the rope leads on the pulley there is a small amount against the upper coil, which is an objection. Also, to obtain good results the speed must be rather slow; practically, it would hardly be possible to go more than three miles an hour.

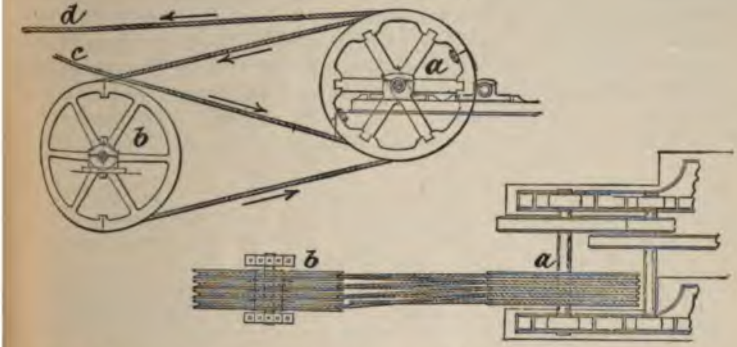
(*c*) *Grooved Pulleys.*—In order to get rid of side friction and prevent the slipping which takes place on taper C pulleys, a series of parallel grooves are put in the main driving pulley, and a similar pulley with one groove less, placed some distance away, the rope being wound from one to the other, each coil having a separate groove to work in. As each coil only passes half round the circumference, and as the second pulley is not a driver, but a follower, the rope has little grip, and consequently several grooves have to be employed on each pulley. To meet this objection, the rope is frequently taken from one pulley to the other in the form of the figure ∞, but although this reduces the number of coils, the rope is bent backwards and forwards, for it passes under and over the pulley. This not only injures it, but shortens its life, as compared with a rope always coiling round a wheel in the same direction.

Another method to lessen the number of coils, is to drive both pulleys, which is the common procedure on cable tramways. No matter, however, whether both pulleys are driven, or whether one is a follower, they only work properly when the grooves are of equal diameters. When new, this condition is possible, as the pulleys can be turned in a lathe. The greatest strain during working naturally comes on the first groove, which is therefore subjected to more wear than the second, while the latter also wears far more than the third, and so on. By such action the grooves not only increase in depth but do so unequally. From the time the rope passes into the first groove, to the time it leaves the last one, no slipping can result. It is also evident that when the wear in the grooves has progressed to such an extent as to make a difference in the diameters of the first and the last one, the speed of the rope is governed by that of the groove having the smallest diameter (the going-on side), and a point on the circumference of the largest groove will obviously travel faster than this. As it is impossible for the rope and *part* of the pulley to travel at different speeds, a grinding action between the pulley and the rope is set up, and the latter rapidly wears out. To show the extent of the wear in the grooves, it may be stated that after three years' wear, those in the leading drum of a cable tramway line measured respectively, $2\frac{1}{2}$ in., $2\frac{5}{8}$ in., $2\frac{5}{8}$ in., $2\frac{7}{8}$ in., 3 in., and $4\frac{1}{16}$ in. deep.

When the grooves are fixed together as in ordinary pulleys, each groove tightens one coil of rope on the other, until when the last groove is reached, the strain amounts to so much that it has in actual cases sometimes broken the pulley, or in others the rope.

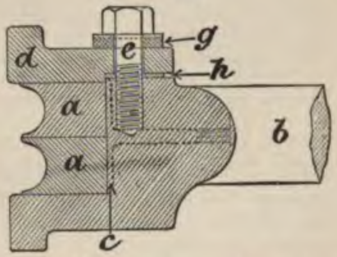
For such reasons, instead of the second set of grooves being made in one solid pulley keyed fast to the shaft, a number of separate pulleys running loose on a bearing are employed, this being the form adopted at Lye Cross Pit. A pulley 7 ft. diam., having five grooves, is keyed on to the third motion shaft (*a*, Figs. 243 and 244), and four loose pulleys, *b*, are threaded on a shaft 15 ft. away. The in-going rope, *c*, is led on to the underside of the first groove on pulley *a*, coils half round it, and passes on to the first loose pulley at *b*, and then back again to the second groove on pulley *a* and so on, until it finally leaves the last groove on *a* and passes away at *d*. By such means the wear on the driving rope is reduced to a minimum, for the second set of loose pulleys can move at varying velocities, and so accommodate themselves to the different speeds required by the unequally sized grooves of the solid driving wheel. The objection is, that as only one pulley is driven, a large number of grooves have to be employed where the load to be moved is a heavy one.

FIGS. 243 AND 244.



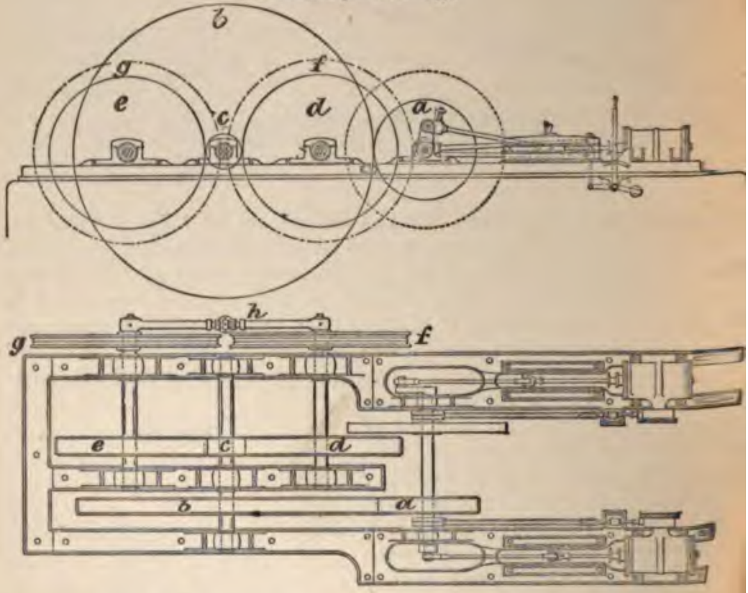
The Walker Differential Pulley, adopted at Bell End Pit, completely gets over all difficulties. Briefly described, it consists of a series of loose rings (*a*, Fig. 245), threaded on to an ordinary pulley, these rings being grooved to receive the rope. Both pulleys have loose rings, and both are driven, the second pulley having one less groove than the first. The flange, *d*, on one side of the pulley is removable, and secured in position by a series of bolts, *e*, indiarubber washers being provided at *g* and *h* to prevent the bolts becoming loose during working.

FIG. 245.



The peculiar point appears to be, that all the grooves are loose. At first sight it would be thought that at least one fixed groove must be provided to obtain the required grip; but this is not necessary. The explanation appears to be that the pressure of the rope in the groove of each individual ring, is transferred to the underside of the ring, hence the friction is just as great there as it would be under the rope if the pulley had solid grooves. Each ring adjusts itself to the unequal strain on the rope, or wear in the groove, and constantly accommodates itself to these conditions whilst in motion. The fact that the ropes equalise themselves on the rings gives each wrap its proportion of duty, and there is no necessity to secure any of the grooves. It is essentially a friction drive, with each ring accommodating itself as explained. The rope never moves on the grooves, as is proved by the fact that when it is at work the impression of the rope is left in the oil at the bottom of the rings, which conclusively shows that no slipping takes place. The bottom and sides of the rings are thoroughly lubricated by automatic grease-cups, inserted in a hole, *b*, in the underside of the rim of the pulley, a groove being provided opposite each hole, as shown at *c*.

FIGS. 246 AND 247.



The complete design of what may be taken as the most modern type of endless rope haulage plant, as adopted at Bell End Pit, is illustrated in Figs. 246 and 247. It consists of a pair of 16 in. cyl. engines by 2 ft. 6 in. stroke. On the crank shaft is a pinion, *a*, 5 ft. diam., gearing into a crown wheel, *b*, 15 ft. diam. on the second motion shaft. This is provided with three bearings, and on it is keyed a pinion, *c*, 2 ft. diam. gearing right and left into crown wheels, *d* and *e*, 7 ft. 6 in. diam., each keyed on to third motion shafts provided with two bearings, one of which is carried on a special bed-plate, while the other is situated on a prolongation of the right-hand engine bed-plate. The two third-motion shafts overhang their right-hand bearings, and on the outside is keyed two Walker differential pulleys, *f* and *g*. The object of this is, that at any time required the loose rings can be taken off, cleaned and oiled, or anything done to the rope without interfering in the slightest degree with any portion of the engines. To take the outward thrust, an adjustable strut, *h*, connects the two third-motion shafts; this is made in halves, connected by right- and left-hand threaded screws. Such arrangement takes off a great deal of the strain, which would otherwise come on to the right hand bearings.

Arrangement for taking up Slack Rope.—Successful working is influenced, to a great extent, by the arrangement for taking up "slack," and at the same time putting enough tension on the rope to prevent any slip on the driving pulley. Ropes lengthen with use, and, in addition, the varying inclination of the plane influences their tightness, or otherwise. Tension carriages should always be placed at the lowest end of the road; the full rope is led on to the driving pulley, then to the tension pulley, and passes away as the empty rope. Naturally, the pulling, or full rope, is always tight.

FIG. 248.

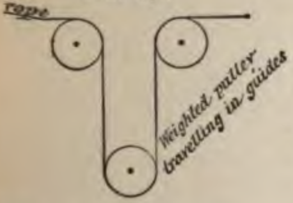
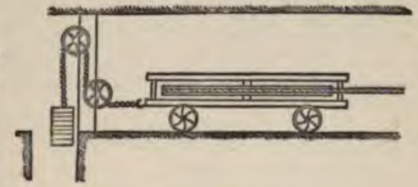


FIG. 249.



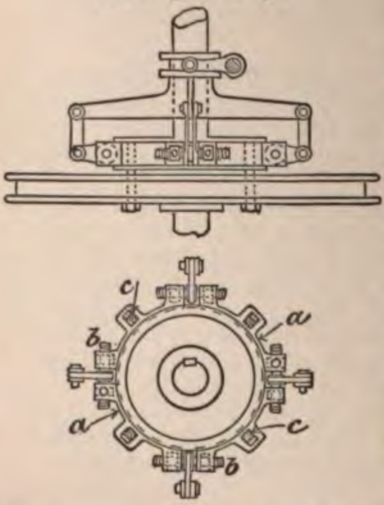
Sometimes this tightening pulley is firmly connected to a screw —it may just as well not be applied at all. What is wanted is some arrangement that gives and takes, and automatically accommodates itself to the varying load. This may be done in many ways. One form is shown in Fig. 248, which, however, is not recommended. Long experience has proved that the life of ropes is considerably decreased when the wires are alternately bent in opposite directions. The better plan is to carry them half round a pulley on a carriage, which can be either weighted and travel on an incline, or it may be on the flat, with a weight attached behind by a length of chain, this weight exercising a direct pull on the waggon (Fig. 249).

The heavier the load on the rope, the heavier should be the weight on the tension waggon, and *vice versâ*. The weight giving the best results is easily determined by experiment, and when once found, need not be varied unless the load on the rope increases. The pulleys on the tension waggons are often made smaller in diameter than the driving wheel, but the far better plan is to make them the same size. Indeed, every main pulley around which the rope coils should be of equal size throughout—one pulley should be a duplicate of another.

Clutches for Working Branches.—It has been often stated that branches cannot be worked with such ease in the endless rope system as with some others, but it is difficult to see why such an opinion should be held. Indeed, the number of branches may be unlimited, if each pulley is able to be thrown in and out of gear by a clutch arrangement. In some cases, the rope along all the branches and main roads is made in one continuous length, and a stoppage anywhere stops the pit.

Numerous clutches are in use. In the ordinary forms there may be a cone sliding into a conical box, or a series of lugs on the pulley fitting into a sliding coupling box. The efficiency and life of the ropes (which mainly affect the cost) depends on the speed at which they are run, and the freedom, or otherwise, from jerks or strains, and neither the cone nor claw clutch should be used, if the duration of the ropes is to be secured. Supposing the main rope to be travelling at its normal speed, and a branch thrown into gear; with the ordinary clutches,the branch rope has to suddenly take the speed that the main rope is travelling at, a very serious strain is thrown upon it, and often something breaks. On the other hand, if it be desired to throw a branch out of gear, it can seldom be done without stopping the main rope. Cone clutches often "jam," and cannot be got out anyhow.

FIGS. 250 AND 251.



Fisher's Clutch.—To overcome these disadvantages, friction clutches have been designed, a very successful one being that invented by Mr. Henry Fisher. It consists of a driving drum, firmly keyed on to the shaft. Around the periphery of this drum is arranged a series of segments (*a a*, Figs. 250 and 251), connected by right- and left-hand screws, *b*. An arrangement of levers is provided, by means of which these screws can be turned. If they are turned one way, the segments close together and grip the drum; if the other way, they open and leave the drum. The number of segments is generally three, sometimes four, and in the centre of each is an oblong hole, in which is inserted a square pin, *c*; the other ends of these pins pass into the arms of the driving pulley. The drum, being keyed to the shaft, is always revolving; the driving pulley is loose, but attached to the friction segments through the pins, *c*. If these segments are tightened on the drum, practically they become part of it, and revolve, carrying with them the driving pulley. The amount of friction, or grip, is determined by the amount of rotation given to the screws, and can be so regulated that sufficient pressure is only exerted to drive the pulley under its normal load. Should a tub come off the rails, or any excessive load be thrown on the rope, the clutch gear should slip. Strain is therefore totally avoided.

The same thing takes place when a branch is thrown into gear. When the segments are first tightened, considerable slip takes place, the branch moves off at first very slowly and gradually increases in speed as the inertia of its load is overcome, until it travels at the same rate as the main rope. As soon as it does this, a very good plan is to slack the segments on the driving drum until only just enough grip is given to drive the branch rope.

The only drawback is its cost. It is very carefully made, the friction parts are bushed with copper to get more adhesion, and there is a lot of fitting work. Its economy and advantages are indisputable, but it is possible to purchase economy too dearly. Many other friction clutches exist which do not, perhaps, give such satisfactory results, but their cost is so much smaller that, except in the more important situations, their use is recommended.

Bever and Dorling's Clutch.—In this form, what might be called a brake flange is attached to the driving wheel. Inside this flange is an inner split ring. The bearing surface of the ring and the brake flange are each carefully turned. On the driving shaft is a collar, which can be slid up and down, but is forced to revolve with the shaft as it travels over a long key. To this collar is attached an arm, and to one end of the arm a wedge, which, when the clutch is out of gear, only just enters the slit in the split ring. To throw the clutch into gear, this collar is moved towards the driving pulley, and in doing so the wedge is driven into the split ring and expands it, causing it to grip the brake flange and so turn the pulley. The principle is exactly the same as the Fisher and Walker clutch, but as the pressure is only exerted at one point its action cannot be so perfect.

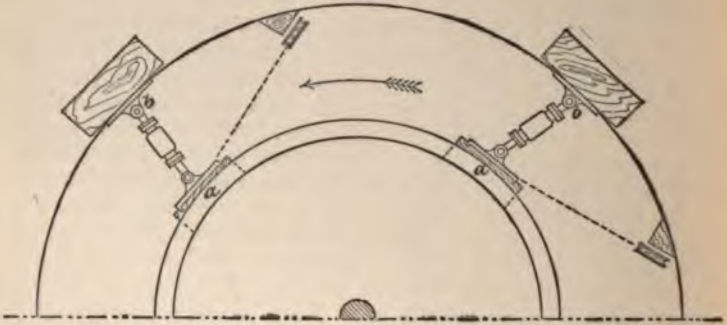
Edmeston's Clutch.—This is the same as Bever and Dorling's, except that the split ring is expanded or closed by the aid of one right- and left-hand screw instead of a wedge.

Brakes for Branches.—When a branch road is thrown out of gear, if its gradient is a steep one, the tubs may continue moving, even after connection with the main haulage has been broken; this only takes place when the inclination is such that the road is nearly self-acting.

Even when such motion is in the same direction as in general (that is, *towards* the shaft) such continuation is objectionable, as, unless the rope were required to stop, it would not be thrown out of gear. Where the gradient is in favour of the load, an ordinary band brake is usually arranged, so connected that it is put on as the clutch is thrown out of gear.

Where the gradient is against the load, and the tubs have a tendency to run back, a most ingenious brake is applied by Walker Bros., and has been working with great success at Lye Cross Pit. Four brake blocks (*a*, Fig. 252) are arranged at intervals around the pulley, and are pivoted about the points *b*. Each is provided with a right- and left-hand screw to allow for adjustment, and to take up wear. These brake blocks are *not* at right angles to the brake rim, but slightly inclined to it, and are pushed away from the wheel so long as it turns in its normal direction, indicated by the arrow, but are kept up to their work by the pull of a small weight. When the branch is thrown out of gear, the moment the wheel starts to run back, the arms carrying the brake blocks try to take a position at right angles to the brake rim; but as this is shorter than the inclined distance, the blocks are wedged against the brake rim and prevent the pulley from running back. In the illustration, as long as the pulley turns in the direction indicated by the arrow, the brake keeps off, but immediately it attempts to go the other way the four arms endeavour to take a position at right angles to the circle *a a*.

FIG. 252.



Ropes Under and Over Tubs.—Two systems of endless rope haulage are in use. In one the rope travels over the tubs, in the other under them. The advantages of the former are, the rope is always carried above the ground, and is not dragged on it, causing friction, wear and tear, and less life to the ropes, and all the machinery is overhead and can be easily inspected. The disadvantages are, that the tubs cannot be loaded high, as is the practice in some districts, without attaching to the tub means for carrying the rope, which not only leads to complication, but introduces another possible cause of failure. This disadvantage may be, and is, avoided by attaching the rope to the sides of the tubs; but, inasmuch as the pull is not in the centre of the load being moved, frequent derailments result. With the rope over the tub, curves are not easily worked. If any exist, they should be made as sharp as possible, and a good large guide pulley placed at the bend. Practically, every curve with the rope over the tubs requires an additional man, as it is not safe to allow the tubs to work round without supervision. For a day, perhaps, everything may go right; but one accident costs more than a man's wages for a week. If the rope is under the tubs, any amount of curves may be worked easily; but here they should be made as large and of as wide a sweep as possible. Rollers are placed all round the curve, and the clips easily pass round these, *if the rollers are large in diameter*, and placed near together. For good working they must be the largest size allowable. Automatic detachment of the tubs is a very simple matter when the rope travels underneath, but over the tubs it is only possible with one form of clip.

Arrangement of Tubs.—The tubs may be connected to the rope either in sets or singly. On the branches, one tub at a time is attached, but on the main line, from two to four tubs have to be massed together. Where the tubs are run in sets, from ten to twenty are attached to each other, and only one of them connected to the rope. Such a train requires an attendant, and the chief advantage of this system of haulage is lost—viz., regularity of delivery. Where only one or two tubs are attached at a time, the delivery to the shaft bottom is a model of regularity; the tubs come and go with scarcely any attention.

One or Two Road Systems.—The endless rope system proper requires two lines of rails and a wide road. Where the roof is a good one this is not a disadvantage, except, perhaps, in the closing years of the colliery's life. The nature of the roof in some mines prevents the double line system being applied. The difficulty is overcome by running the tubs in sets, and arranging pass-byes at intervals. An attendant travels with each set, and waits at the siding until the train travelling in the opposite direction arrives there; they pass each other, one proceeds towards the shaft, and the other in-bye. Connection between the set and rope is usually made by a screw-clip attached to a bogie carriage (Fig. 253) on which the train-man rides.

Another plan, which avoids the inconvenience and expense of running sets, is to provide two roads each laid with a single line of rails. In one, the full tubs travel out-bye, while in the other, the empty ones pass into the workings.

For steep gradients, where the load would be too great for a single rope, two may be employed. At Newbattle Colliery, Edinburghshire,* such system is adopted, each tub being connected to two ropes. Although an elaborate arrangement of friction clutches were applied to allow the ropes to automatically adjust themselves, and each take their share of the load, yet such were found unnecessary.

FIG. 253.

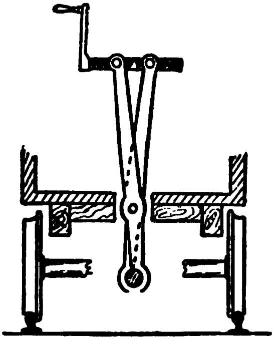
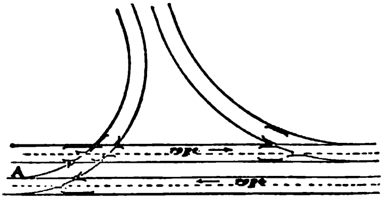
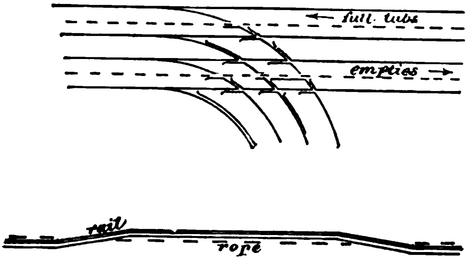


FIG. 254.



Rails at Junctions.—At main stations, where branches are worked, the usual arrangement of switches and crossings is employed, and as the ropes are either above or beneath the road, no provision has to be made to prevent their being injured.

FIGS. 255 AND 256.



For junctions, with under-rope haulage, several methods are used; two of the more general ones being shown in Figs. 254 and 255.

In Fig. 254 the empty tubs are taken off the rope as soon as they have passed the switch at A and are then run back into the junction road, as indicated by the arrow. The full tubs from the workings pass at once on to their proper road, as shown by the illustration.

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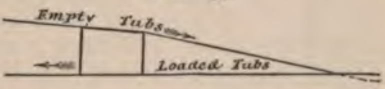
* Min. Inst. Scot. ix. 211.

The better plan is that of Fig. 255. It is more compact and easily worked. The illustration explains itself. In both these figures it will be noticed that small breaks or spaces are left in the crossing rails, and in these the rope generally works. Unless some such provision were made, the rope would receive serious injury from the flange of the tub's wheels as they passed from the junction to the main line, as each wheel would have to roll over the rope as it lay on the top of the rails. To prevent any chance of this happening, not only are recesses provided, but the rails at the junction are raised some 3 in. above the general level, as shown by Fig. 256. Just before reaching the junction, a short length of inclined rail is fixed, followed by level rails at the junction, and then another short inclined piece is inserted, throwing down the rails to their original level. At the junction, the haulage rope is, therefore, below the lower flange of the cross rails, and tubs joining the main engine-plane can do no injury. When a tub on the engine-plane reaches the junction, the clip, which carries the rope a uniform distance above the floor, lifts the rope out of the groove and lets the tub pass without obstruction, the rope falling back into the recess immediately the tram has gone by. Check and guard rails are used at all junctions, as shown by the figures.

For over-rope haulage, no better plan can be adopted than that of raising up the empty road for some distance before the junction, until on arriving there, sufficient height is gained to allow of the construction of a bridge, over which the empty tubs pass either straight on or into the branch (Fig. 257), and *beneath* which the full tubs from the branch are taken. The illustration explains the arrangement, which is preferable to having the crossing on the same level; there is no chance of collision or derailment, and, owing to the height to which the empty tubs are raised, they run freely round the curves, and require scarcely any attention.

FIG. 257.



CLIPS.—Tubs are attached to the rope in many different ways. A good clip should be capable of easy and ready attachment and detachment, should not injure the rope, have few wearing parts, and act equally well on a downhill or uphill gradient.

Clips for "Under" Haulage: *Screw Clip.*—The common form of clip consists of two plates connected together by a screw, and attached to a hook, through which they can be joined to the draw-bar. This certainly holds the rope, but is neither easy to attach or detach.

Smallman's Clip.—The principle of this is the same as that of the screw clip, but the gripping action is obtained in a much easier and readier manner. It consists of two plates (*a a*, Figs. 258

and 259), connected together by a bolt, *b*, in the centre; a lever, *c*, turning about a point, *d*, is provided, its shorter arm being enlarged, as shown at *e* (Fig. 259). This slides along wedge-shaped recesses in the side plate, and, as a result, the lower part of the plates can either grip or release the rope. Adjustment for wear can easily be made by tightening the bolt, *b*. A very powerful grip is obtained, the rope is not damaged, as it is gripped for several inches, attachment is easy, and the clip passes freely round curves. It is, however, rather cumbersome, and cannot be automatically detached.

FIGS. 258 AND 259.

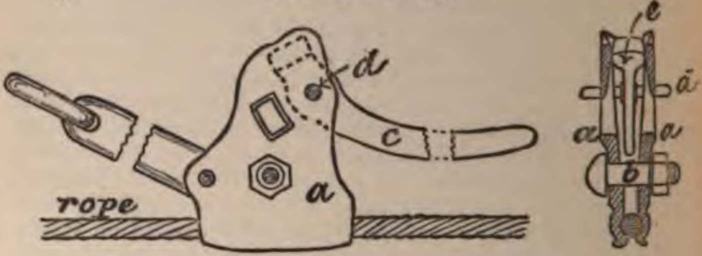
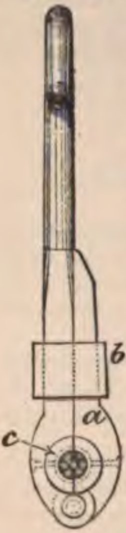


FIG. 260.



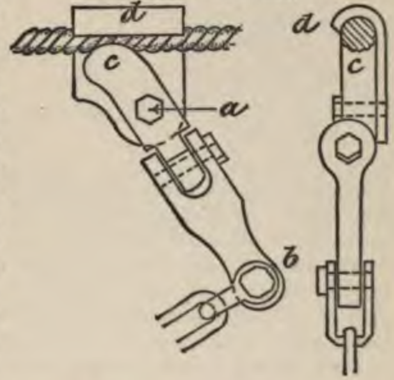
Fisher's Clip consists of a hook having a hinged piece, *a* (Fig. 260), at the far end, which can be doubled back and locked by a sliding collar, *b*; a recess is provided to receive the rope. The hook is placed in the draw-bar, and the clip grips the rope by deflecting a small portion of it. It is essential that the hole through the clip should be the same size as the rope and of softer material, so that it wears itself instead of the rope. To allow this, the recess is provided with bushes, *c*, of soft iron, which are kept in position by rivets, and are easily replaced when worn.

With Fisher's or any similar clip, it is absolutely essential that the rope should have a wire core, if not, it stretches too much, and the clip will not hold. The hook part is made of a very good quality of iron, and is the weakest part, so that in the event of the tub being derailed, the hook straightens out and the rope is not damaged. This clip acts equally well uphill or downhill and round curves, and can be easily and automatically detached in the same way as any other clip which is locked by a sliding collar.

Clips for Over Haulage.—The common method of attaching tubs to the rope is by means of a chain, one end of which is hooked on to the draw-bar of the tub, the other end passed twice round the haulage rope, and then hooked back on to the chain passing from the tub; as soon as the full weight comes on to this chain, the coils get quite close together and form a compact fastening. This attachment is not by any means perfect, although a very convenient one. On undulating gradients, two chains are required—one before and one behind each tub, but both must not be tight at the same time, as in such a case, if the rope was suddenly stretched, the tub would inevitably be lifted off the rails. Wire ropes are in the habit of twisting, and when they do, if the above attachment is used, the chain twists with them, winding up whatever slack portion there may be; consequently, on reaching turn pulleys, or any bend, where the rope is raised higher than its normal position, the tub is overturned, and all succeeding tubs are overthrown until the rope is stopped.

Ward and Lloyd's Clip.—Many of the above disadvantages are overcome by the clip employed at Sandwell Park Colliery. It is exceedingly simple, consisting only of a hinged lever, to the bottom end of which is attached the chain fastened to the tub. (Figs. 261 and 262). The lever works about a pivot, *a*, and immediately the weight of the tub comes on to the end, *b*, the rope is gripped between the top end, *c*, and the curved plate, *d*. The lever is hinged, which allows the clip to fall into the guide pulleys when passing round curves. It has now been in use six years, and has given every satisfaction. It is easily attached and detached, but this cannot be done automatically, and on undulating gradients two clips have to be used for each tub.

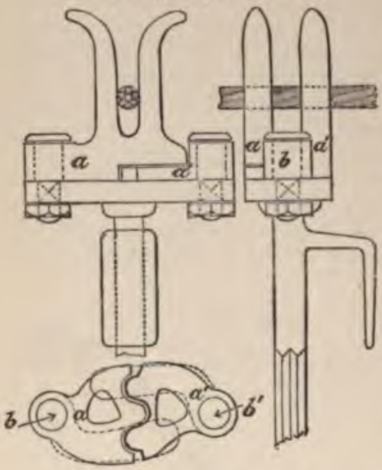
FIGS. 261 AND 262.



Rutherford and Thompson's Clip.—The great advantage of this appliance is that it automatically attaches and detaches, enabling curves and junctions to be worked on the gravity principle, in the same way as with endless chain haulage. It does away with one man or boy at each junction, for with an ordinary clip some one has to be employed to take off empty tubs and put on full ones; while with this one, all that is necessary is that some one should be in attendance to space the tubs, and to lift off the clip from the empties, and attach it to the full ones.

Figs. 263, 264 and 265, which are respectively front and side elevations and plan, show details of the rope gripping apparatus usually employed, which is composed of two Y-forked jaws, *a a'*, mounted and geared together as shown by Fig. 265, so that they can oscillate about the two pins, *b b′*, as centres. As soon as the clip comes into the same line as the hauling rope, the motion of the latter turns the forks slightly about the centres, *b b′*, and causes them to close on the rope and grip it firmly. The stronger the pull, the tighter the grip, hence the clip is well suited for heavy gradients; and as it is attached to the tub through a rigid rod, which is hooked over the top while the other end passes into a small bracket on the front, and as the jaws can move either backwards or forwards it works well on undulating gradients.

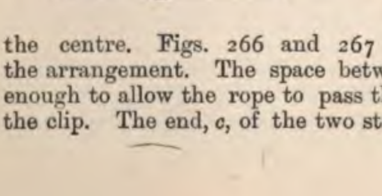
FIGS. 263, 264 AND 265.



The rope can be lifted out of this clip, or dropped into it again, with as much ease as a chain is lifted out of the Y on an ordinary tub, but inasmuch as these clips are not fixed to the tub but are detachable, an arrangement is employed to prevent them being accidentally lifted off when the rope is disconnected.

Automatic Detachers.—Little difficulty is found in automatically detaching any clips of such a type as Fisher's, where the grip on the rope is determined by the position of a sliding collar, because if this collar is lifted up, the clip is released. If the rope and clip be conducted into a groove, having sides arranged on an inclined plane, and if the rope is kept down as the clip passes through, the collar is lifted up.

FIGS. 266 AND 267.



At Nunnery Colliery a very simple appliance is used to perform this action. At the detaching point, two strips of iron are connected at one end by a cross piece, and are pivoted about pins near the centre. Figs. 266 and 267 show plan and elevation of the arrangement. The space between these two strips is wide enough to allow the rope to pass through, but not the collar on the clip. The end, *c*, of the two strips of iron cannot be pressed down because the other end, *a*, is under the rope, consequently the collar of the clip has to slide up the inclined plane and is gradually lifted, releasing the rope.

An apparatus of more elaborate, and perhaps more sure character, has been designed by Mr. J. F. Lee, of Castle Eden Colliery. It consists of a groove having inclined sides, out of which the rope and the lower part of the clip cannot be lifted, as each side is formed of an angle-piece (Fig. 269). The continuation of the jaws is made by two levers (*a*, Fig. 268) kept up by a weight, *b*, but when the pressure becomes excessive they may be pushed down, the object of this being that the levers can accommodate their height to suit the varying positions of collars on different clips. The rope and lower part of the clip pass underneath the jaws, which taper towards the point of exit; the

FIGS. 268 AND 269.

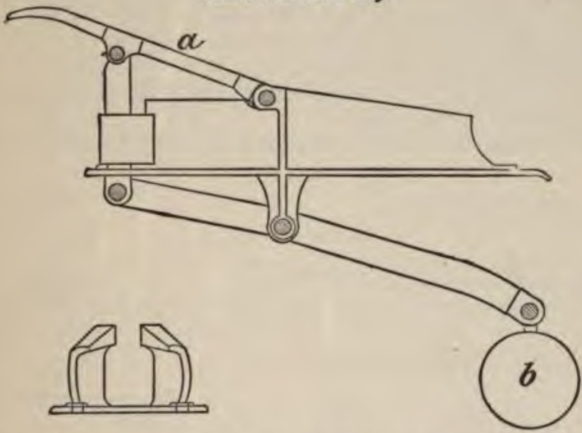
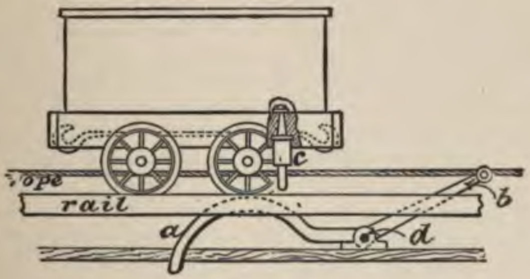


FIG. 270.



collar passes up the inclined plane and is lifted, thus detaching the tub. To prevent any chance of failure, the collar of the clip is provided with a flange.

At Skelton Park Colliery* the ropes are attached to a simple hook beneath the tubs, as the gradient is slight, and the weight is sufficient to haul them along. They are detached by an apparatus, consisting of a lever (*a*, Fig. 270) working between split rails, and depressed by the passing tubs. This turns the shaft, *d*, raises the lever, *b*, and lifts the rope out of the hook, *c*. At the same time, a slight divergence is made in the line of rails, causing the hook to move aside from the rope, which then drops when released by the lever, *b*.

With Rutherford and Thompson's clip, detachment is obtained by an appliance which consists of a holding-down pulley (*a*, Figs. 271 and 272), and of two inclined guide-blocks, *b*, one on each side of the rope, the spaces between them being such that the rope can rise up, but that the forks of the clip catch the under side. As a tub and its clip come to the detacher the rope gradually gets higher and higher, tending to lift the clip out of its socket, but is prevented from doing so by the two guide blocks, *b b*, which catch the top of the forks. Ultimately the rope is lifted completely out, and the tub runs away. With a clip having a very tight grip, a jerk is thrown on the rope by such action, and to prevent this extending down the road to the tubs further in-bye, a movable holding-down pulley is placed a short distance away which checks vibration in the following manner:—A shaft (*a*, Fig. 273) is fixed across the road above the rope and on it are keyed three arms, one carrying a holding-down pulley, *b*, the second having a weight, *c*, at the end of a lever, while the third, *d*, hangs downwards. The action of *c* is to keep the pulley firmly on the rope, and that of *d* to lift the pulley when the tubs are passing, this being necessary, or the clips would catch it and break.

FIGS. 271 AND 272.

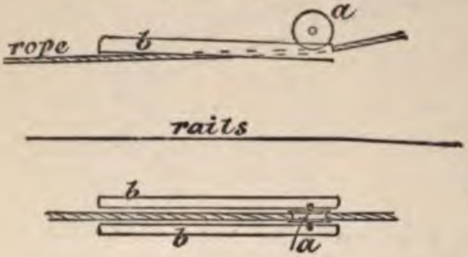
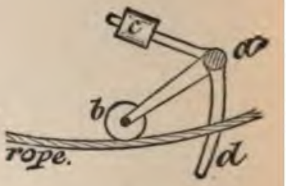


FIG. 273.

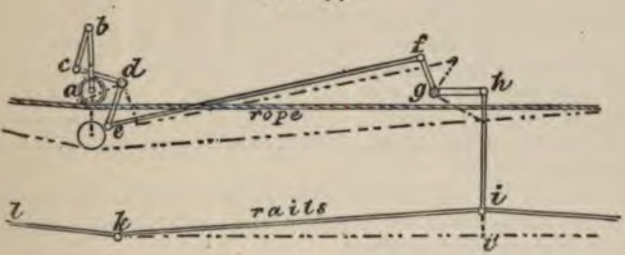


* N. E. I. xxxi. 105.

The tubs which are travelling in the direction from *a* to *b*, push aside the arm *d* which hangs down before them, and on doing so, turns the shaft, *a*, round, and lifts up the pulley and weight, which fall again immediately the tub has passed.

At curves, where the continuing road is on a downhill gradient, the tubs run round and attach themselves to the rope again immediately this comes low enough to grip the clip, but where the gradient rises out-bye other means have to be employed, as the rope tends to get further away from the clip. It is impossible to deflect the rope far enough downwards with a fixed guide pulley, as these have to be placed high enough to clear the clip. The movable one just described is inadmissible here, as the tubs being detached from the rope, are only moving with the force due to the inclination of the road, and would not have sufficient power to lift the lever and weight. The ingenious appliance shown in Fig. 274 has been designed to meet such cases. A pulley, *a*, is fixed at such a height as will allow the tub and clip to pass beneath when it is in its normal position. This pulley is not a fixture, but it is suspended from a shaft, *b*, fitted with guide blocks, and connected by crank levers, *c d e*, and *f g h*, and the links, *b c*, *e f* and *h i*, with the rails forming the road at this point. There are two sets of levers, one on each side of the rails. The rails, for a distance of about 12 ft., are carried on a platform hinged at the point, *k*, and by means of a balance-weight take the inclination shown at *i k*. The tubs when detached from the rope, run down the slope, *l k*, pass beneath the pulley, *a*, and continue by the momentum they have gained up the slope, *i k*; their weight, however, over-balances the counterpoise. The platform descends about the centre, *k*, takes the position, *i′ k*, pulls down the link, *h i*, moves over the two cranks, and depresses the guide pulley, *a*, and the rope to such a distance that it is caught by the clip, and the tub consequently moves away. As soon as the tub has gone off the platform, the counterpoise raises it again and the guide pulley, so that the whole appliance is automatic. The points *d*, *g* and *k*, are fixed, the remainder movable. At the moment of

FIG. 274.



attachment of the tubs to the rope, the different parts of the apparatus occupy the position shown by the dotted lines; the travel of the pulley, *a*, is about 10 in.

Threading the Rope.—It is rather a difficult matter to put on the first rope of a new application of endless rope haulage. As supplied by the manufacturers, ropes are very carefully coiled and should be unwrapped from the *outside*, care being taken that no "slack" is payed out, or the rope will at once kink and spoil itself. If a new rope is replacing an old one, the threading is an easy matter, but one requiring care. First of all, the old rope is cut through, and one end of the new rope attached to the old one, but in between the two ends a swivel must be placed. The object of this is to take out all the twist in the new rope; unless this is done, difficulty will afterwards be experienced in the working. The coil of rope is placed on a turntable to which some moderately strong brake power can be applied. The engine is then started and the old rope moves away, dragging with it the new one, the latter following the former, and occupying its place. When the two ends come together, they should be strained as tight as possible, which is done by attaching blocks, and, at the same time, the tension pulley is braced up as close as can be, as the ropes invariably stretch in use.

Unless an old rope is available, horses have to be employed; their movements are very irregular, and there is considerably more chance of damaging the rope.

Comparison.—If a good representative of each type of haulage is taken, the cost per ton per mile is about the same in all of them. To a great extent, the cost depends on the number of junctions and branches, because attendants have to be provided at these points to attach the tubs. In comparing the cost of one system with another, it is usual to reduce the cost to a uniform distance hauled of one mile—that is to say, if the cost is twopence per ton per half mile, a simple proportion gives fourpence per ton for one mile, but although some uniform distance must be introduced, yet it does not give a fair comparison in every instance. Take, for example, an endless rope or chain plane, exactly a mile from the beginning to the end with no junctions. One man at each end should perform all the labour of taking off and putting on the tubs, and the cost per mile, on the one mile length, would be very small; but if, in another case, there are four junctions in a similar length of plane, each of these junctions will require the services of an attendant, and the labour cost will show very much higher than in the former case, providing the same quantity is hauled, and yet the two planes may be exact facsimiles of each other, and both be laid out with the same care and labour saving appliances.

Another point to which attention should be directed is that in published statements of costs, many estimates entirely overlook some part of the first cost of the plant. Hauling engines cannot be worked without steam, and the extra amount for additional pulleys, fittings, pipes, &c., caused by adding haulage machinery, should be charged against the plant. Then again, the stores' charges for the machinery should be noted.

The most careful experiments which have ever been made to determine the cost of different systems were those carried out by the North of England Institute.* This was, however, many years ago. The endless rope system was then in its infancy, while little improvement has since taken place in either the tail rope or endless chain systems. This report strongly brought out the merits of endless chain haulage, so far as regards its ease and cost of working, but friction clutches, automatic detachers, improved driving pulleys, and the other similar labour-saving appliances of modern endless rope haulage were then unknown. At that time, a life of one or two years in a haulage rope was considered a very good performance; at the present time seven to nine years is by no means an unusual occurrence. At many collieries the rope cost per ton-mile does not exceed 0.2*d*.

The great advantage of the endless rope system is the perfect regularity of the delivery. The tubs come one at a time at regular intervals, and are easily dealt with; in addition, the full tubs going down inclines assist in pulling the empty tubs up. Both these advantages are common to the endless chain system, but the disadvantages of the latter is the enormous weight of the chain and its liability to break, especially on long planes. For surface work, the endless chain possesses one advantage, inasmuch as it is little affected by the action of the weather, but underground this advantage disappears.

With the tail rope system the tubs work in sets, and, therefore, travel at a high velocity, fifteen to twenty miles an hour being often reached. The delivery is intermittent; a train of from fifty to sixty tubs is brought into the pit bottom at a time, and men have to be there to deal with the set; on its arrival, all is hurry and confusion for a few minutes until the empty set has been despatched to the workings, and then the men have little to do. Should a tub become derailed when travelling at this speed the damage done is considerable. With an endless rope, travelling at only two or three miles an hour, there is little possibility of derailment, and even if this does occur, the damage done is slight. With the tail rope system, less length of rail is required, but a larger pair of engines are necessary than for endless rope, because in the former case they have to be powerful enough, to deal with the *heaviest* load up the *heaviest* gradient, have to travel at a very high speed, and derive no benefit from the counterbalancing effect of gravity on undulating gradients. Their action is intermittent and they require an engineman always in attendance. It has been pointed out that main and tail rope haulage possesses an advantage over the other types, inasmuch as the men may ride in-bye, with the result that their time at the face is increased. The advantage is, however, not a large one, as only a small proportion of the total men employed can be transported in the first set travelling in-bye. This is practically the only one available, as before the second set is ready, the remaining men could walk to their work.

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* Vol. xvii.

With the endless rope system, the constant attendance of an engineman can be dispensed with by arranging a clutch gear at the bottom of the pit, where the main strap rope terminates. This point is the principal junction of the pit, and men have to be there to attach and detach the tubs. If a signal comes from the workings to stop the main rope, one of these men can easily turn the wheel which disconnects the clutch gear, and the engine on bank may continue running. The author is not aware where the services of an engineman have been dispensed with at a hauling engine, except in the instances of two of the collieries under his charge. By spending £100 on a good efficient clutch gear one engineman looks after three continuously running engines—*i.e.*, hauling, fan, and shop machinery, and not the slightest hitch has ever occurred. The only objection to this system is the possibility of some accident happening to the shaft rope, but an experience of eight years does not support such contention.

The author has at work every system of haulage; but the one that stands pre-eminent is, undoubtedly, the slow moving endless rope, with the tubs attached at regular intervals. This appears to be the common experience, as nine out of every ten systems which have been put to work during the last ten years are endless rope, with the probable exception of the North of England, and even there this system is rapidly gaining ground.

An endless rope can be employed anywhere, although to obtain the best results the roads should be laid out to suit it. The only objection against it is that a double road is necessary to obtain its advantages to perfection, and that double roads are expensive to maintain where the roof is bad. As previously pointed out, even this disadvantage may be, and is, removed by employing two roads, each laid with a single line of rails, one for the full tubs and one for the empties.

Locomotives.—At best, haulage by locomotives is not to be recommended, as neglecting the dangers of and the difficulties of dealing with the smoke, steam, &c., the system has the disadvantage of being intermittent in the matter of supply. The engines have to be small ones, and are not only very expensive in up-keep, but are very liable to derailment. Locomotives worked by steam have been applied in English collieries and in the American anthracite mines. Locomotives worked by compressed air have been tried on several occasions, but have never given satisfaction.

Electric Locomotives.—The first locomotive worked by electricity was applied in 1882 at Zauckerode Colliery in Saxony. The current is conveyed along the roof of the roadways by a ⊥ iron conductor, and is transmitted to the motor by a conducting piece which slides along the ⊥ iron. The locomotive has worked most satisfactorily ever since its application, and performs the work more cheaply than horses which it replaced. Altogether, there are four electrical locomotives in German mines, and Mr. K. Eilers* states that the cost of tramming with electricity is at Stassfurt and Zauckerode, 75 per cent., and at Hohenzollern Colliery, 67 per cent. of what it originally was when horses were employed.

At the present time (1893) the only electrical locomotive employed in English mines is that introduced by Mr. G. B. Walker at Wharncliffe Silkstone,† where the engine does not depend for its grip on the friction between the wheels and the rails, but gets a direct pull on a fixed rope. The latter is fixed at either end and lies parallel to the road, and is passed over a sprocket wheel or friction clutch geared in a suitable manner to an electric motor on a trolley. The road is 500 yds. long, the inclination averages 4 in. to the yard, and the rolling load is approximately 4 tons.

Several installations have been made in American mines, and Mr. H. C. Spaulding‡ states that the Thomson-Houston Co. have recently constructed the largest in that country. The locomotive is 60 H.P., weighs 21,600 lbs., is 3 ft. gauge, and has a maximum speed of 10 miles an hour. The armature speed is 1020 revolutions per minute, and the locomotive is 3 ft. 3½ in. high, 3 ft. 6¼ in. wide, and 12 ft. 6½ in. long.

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* Amer. Inst. M. E. xx. 365.

† Inst. C. E. civ. 116.

‡ Eng. and Min. Jour. Oct. 10, 1891, p. 434.

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AMER. INST. M. E.: *Wire Rope Haulage and its application to Mining*, F. C. Roberts, xvi. 213; *Electricity and Haulage*, F. A. Pocock, xviii. 412; *Electric Locomotives in German Mines*, K. Eilers, xx. 356.

N. STAFF. INST.: *A few remarks on Underground Haulage*, J. R. Haines, vi. 194.

REV. UNIV.: *Note sur le trainage automoteur par chaine flottante des mines de Fillols*, C. Blanchart (2e Série), vi. 142; *Note sur un système de plancher mobile en fer applicable à l'exploitation des tailles chassantes par plan incliné*, C. Ruidant (3e Série), ii. 80.

ANN. DES MINES: *Note sur quelques details de plans inclinés automoteurs*, M. Villot (8e Série), xvi. 409.

FED. INST.: *A short description of the Underground System of Haulage at Mitchell Main Colliery*, T. W. H. Mitchell. iii. 147; *Electric Haulage at the Cannock and Rugeley Collieries*, R. S. Williamson, iii. 483; *Electric Haulage at West Cannock Colliery*, W. Wardle, iii. 486; *Underground Haulage by Endless Rope at Ansley Hall Colliery*, W. G. Phillips, iii. 847; *Underground Haulage at the West Riding Collieries, Normanton*, W. E. Garforth, iii. 960; *Endless Rope Haulage at Thorncliffe, Rockingham and Tankersley Collieries*, W. Hoole Chambers, iii. 970.

CHAPTER IX.

WINDING.

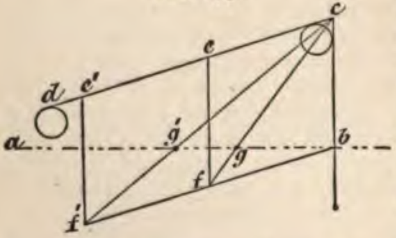
THE material having been brought to the pit bottom, the next thing is to convey it to the surface. This is done by placing the tubs in a suitable apparatus called the cage, to which one end of a rope is connected, while the other is attached to, and wound round, the drum of an engine at the surface. On reaching the top, the full tubs are taken off and replaced by empty ones, and the cage then descends.

Pit Frames.—As some support has to be provided for the rope, a pit frame with pulley attached is used for such purpose. At modern collieries with large winding machinery running at quick speeds, one stroke of the engine means a considerable lift of the cage, and unless the head-gear pulleys are placed a good height above the surface level, and the engineman is very careful, the cage may be brought up against the pulley, and over-winding take place. In addition, the great majority of collieries are provided with screening appliances, which are inclined so that the coal may run down them, and, as the trucks into which the coal is loaded stand at the ground level, the landing place has to be some distance higher up. A further height is therefore given to the pit frame, and it is quite common to find the head-gear pulleys 60 or 70 ft. above the ground. These erections are constructed of different materials. On the Continent, towers of masonry are employed, but such procedure has never received favour in this country, nor, indeed, a very extended application anywhere else. The material mostly in favour, until recently, was wood, wrought-iron was afterwards employed, and, as in every other branch of engineering, the use of steel is rapidly becoming common.

Before describing the method of construction, perhaps it would be best to refer to the general method of design. The structure, as a rule, consists of six main parts: (1) two vertical upright legs (to carry the weight to be lifted); (2) two front vertical legs (for affording support to the cross timbers carrying the guide ropes); (3) two back legs (to prevent the whole structure being dragged over by the pull of the winding-rope going to the engine). These main legs are braced and connected together by various cross-pieces, added to give general stability to the whole structure. There is nothing particular in the four legs of the front framework, except that they enclose a wider space at the ground level than at the top, the object of such being to prevent them toppling over sideways; but the position of the back legs is of considerable importance. Their bottom ends have to be placed at such a distance from the front legs as will effectually prevent any chance of the frame being pulled over towards the winding-engine. The proper position of these back legs is very easily determined, although in many instances they are placed anywhere but in the right position. Often they are carried so far towards the winding-engine that additional vertical supports have to be provided underneath them; no advantage is gained by this, indeed it only introduces an element of instability, as the legs may not be strong enough even to carry their own weight. The strain on the pit frame, both as regards direction and amount, is the resultant of two forces. First of all there is the weight—viz., the weight of the tubs, coal, cage, and the rope hanging down the shaft, which is a moving, or live load, and, therefore, throws more strain on the structure than if it were an inert mass. The other strain is that coming from the winding-rope, which has to exert sufficient power to lift up the weight hanging in the shaft at a certain velocity. The direction of the pull due to the weight in the shaft is always vertical, but the direction of the one due to the winding-rope may be at any angle to the vertical, its direction being determined by the height of the head-gear, and the height of the drum above ground level, and its distance from the centre of the shaft.

The relative position of the back legs to the front ones is determined by the principle of the parallelogram of forces, and may either be worked out by calculation or graphically. Supposing *a b* (Fig. 275) is the ground level, *c* the pulley, and *d* the drum of the winding-engine; *c b* is the direction of the force acting downwards, and *c d* that due to the winding-rope, and which tends to overturn the structure. Under ordinary circumstances the amount of force acting along *c d* must be equal to that along *c b*. Take the distance *c b* as being equal to the amount of force acting in that direction, and lay off along *c d* a distance *c e*, equal to *c b*. From *e*, a line, *e f*, is drawn parallel to *c b*, and another line, *b f*, is drawn parallel to *c e*. The direction and magnitude of the resultant force will be given by the line *c f*, the diagonal of the parallelogram. In the case under consideration, the back-

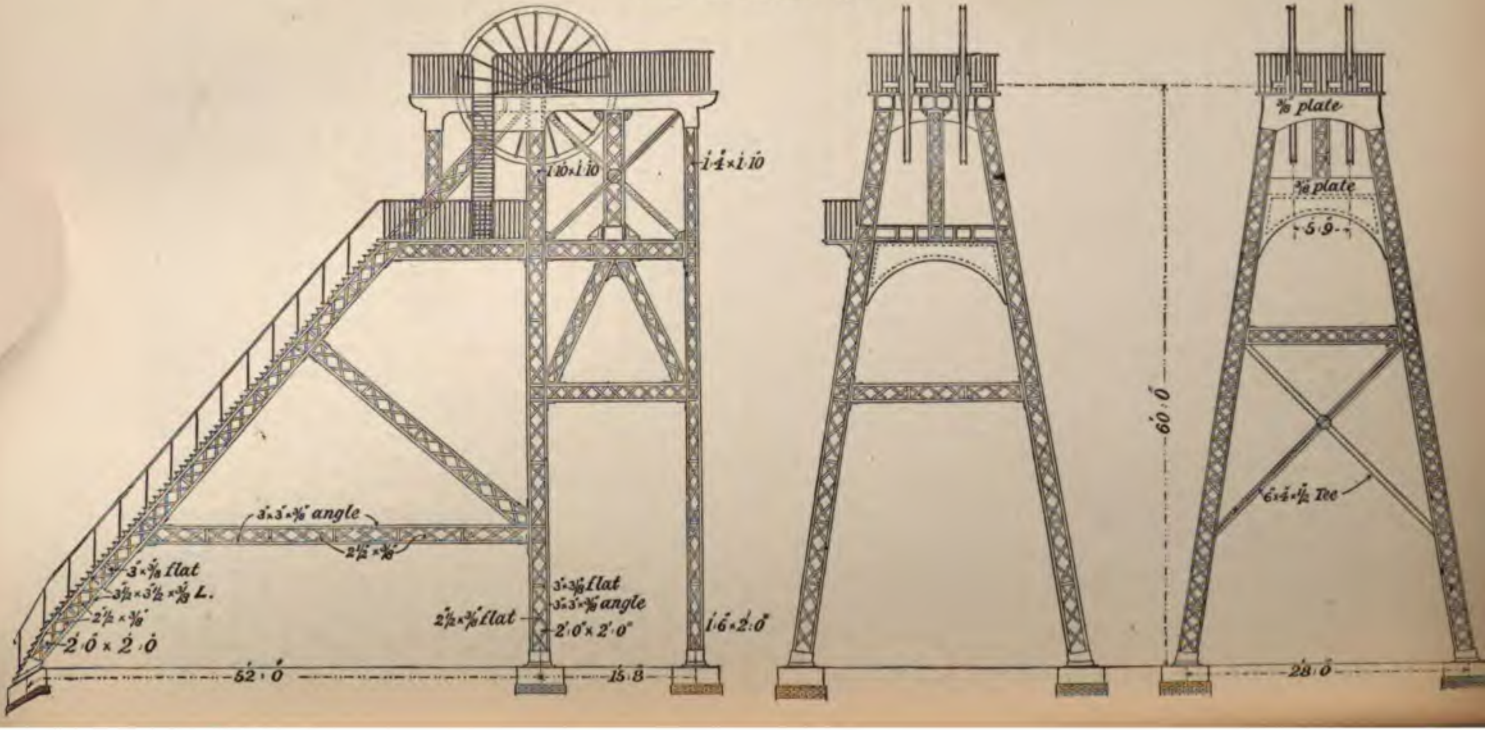
FIG. 275.



stay should reach the ground at the point *g*, where the diagonal cuts the line *a b*; but, even at the best regulated collieries, accidents happen, and the cage may be drawn violently against the head-gear, or, even without doing this, it is possible for some larger power to be applied along the line *c d* than that due to the weight hanging down the shaft. To be on the safe side, it is preferable to lay off along *c d* a distance *c e'* equal to twice *c b*, *e f'* and *b f'* are drawn parallel to *c b'* and *c d'* respectively, and the parallelogram constructed as before. The point *g'*, where the diagonal *c f'* cuts the line *a b*, will determine the length of the base of the pit frame. In an actual case of over-winding, the weight of the pit frames reduces the likelihood of their being pulled over, and adds to their stability; indeed, it is very probable that unless a detaching-hook is used, either the head-gear would be smashed or the rope broken.

Wood.—Where wood is the material used it is generally pitch-pine, which should be free from sap and knots. The height and position of the back legs having been determined, the strengths of the required timbers are found by calculation, and depend on the height and load to be carried. In side elevation, the front legs are vertical, their position with respect to the centre of the shaft being determined by the size of the pulley, because they come directly under its centre, while the throat of the pulley has to allow the rope to pass down the axis of the shaft. In end elevation, the width at the top is determined by the distance between the centres of the two cages, because each pulley has to lead its own rope on to the centre of each cage. If to the distance between the centres of the cages, be added the distance between the centres of the pulleys' bearings, the length from centre to centre of the two main cap-pieces is obtained. This gives the width at the top. The width at the bottom is determined by the amount of inclination given to the legs, which is usually 1 in 9 or 10. The main legs, both back and front, are braced and connected together by horizontal and diagonal struts, and often too many are introduced. There is no necessity to add one more than is absolutely necessary, as they only weaken the erection by burdening it with additional weight. The structure often rests on two main parallel sills running from the back to the front legs, but such practice is not recommended. These sills rest on brickwork, and dirt and soil accumulate around them, with the result that they are the first part of the structure to get rotten, and, no matter how carefully they are painted, decay cannot be prevented The best plan is to put each leg into a cast-iron shoe (similar to Figs. 276–278), resting on a pillar of masonry, and held in position by tie-bolts. Part of the timber is buried in the shoe, and at the point where the iron ends and the timber first becomes exposed to the atmosphere a crevice exists, through which moisture and damp can find its way. Unless this is prevented, the timber

FIGS. 276, 277 AND 278.



will rot quicker than if it was on wooden sills. To prevent this, the joints should be most carefully filled in with putty and painted, and then a strip of zinc placed all round.

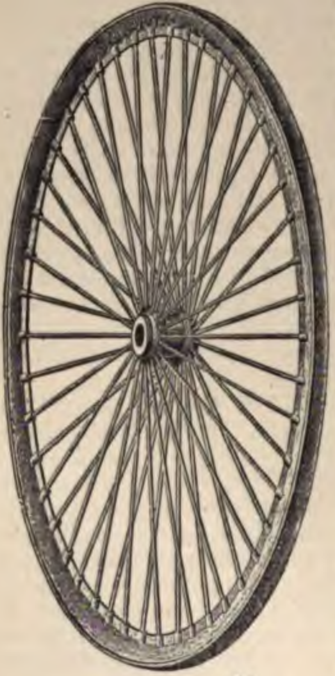
Iron or Steel.—Pit frames have gradually increased in height, and the tendency has also been to raise heavier loads at quicker speeds. It has, therefore, become difficult to obtain timber of the required size and lengths, except at great expense. As a result, wrought-iron erections were first substituted, to be replaced in their turn by steel. The position of the various parts should be the same as if wood were used. On the Continent, a design is employed where the legs are composed of tubular girders braced together by channel section stays, but the general English practice is to construct the legs either of box or lattice girders. A fine example of the latter design is one of the pit frames at Sandwell Park Colliery, the construction of which is shown in Figs. 276 to 278, which are respectively side, front, and back elevations. The general construction and dimensions are given on the illustrations. All the main struts are of lattice girder work, which consists of four angles, one at each corner, connected by diagonal pieces of flat strip; the pulleys are carried by girders, which are of box construction in section, but the sides are lattice work to allow for the adjustment of the pulley carriages. The plates shown in the front elevations are open at the bottom.

As the legs have to bear less weight at the top than at the bottom, it is common to make them taper. With a lattice girder, if it tapers, every set of cross-pieces binding the corner angles together is necessarily of a different length, which increases the cost of manufacture; to remove this disadvantage, the legs have lately been made parallel throughout. By doing this the weight of the girders is slightly increased, and they are stronger at the top than required, but as the cross-stays in each girder are of exactly the same length, each one can be cut and rivet-holes punched from one template, instead of the innumerable sizes which are required with taper girders. The economy of construction, therefore, far outweighs the extra cost of the small additional weight.

As a lattice girder is rather expensive to make, and as of late years it has been possible to roll very long strips of either iron or steel, the box girder form of leg has been adopted in many cases. The one at St. Hilda Colliery, South Shields, may be quoted as an example. It is 75 ft. high and commences at the bottom with a section 18 in. square and finishes 15 in. square at the top. Each member consists of four plates, bound together by angle pieces at the corners. In the main struts, the four plates are $\frac{5}{16}$ in thick, and the angle iron is $3\frac{1}{2}$ in. by $3\frac{1}{2}$ in. by $\frac{5}{8}$ in.

Pulleys.—At one time chains were employed for winding, but, except in the rarest instances, none are now to be found, ropes either of flat or round section being employed. Upon the type of rope used depends the shape of the throat of the pulley, such part being the only variable one, their general design being the same either for round or flat ropes. They consist of a cast-iron boss and rim, connected together by wrought-iron spokes (Fig. 279). The shaft, or "gudgeon," is composed of wrought-iron, having turned bearings. With a view of reducing friction, the bearings should be as small and the pulley as large as possible. The large diameter of the pulley introduces another advantage, as it reduces the bend of the rope, and it is, therefore, not uncommon to find pulleys having a diameter of 18 to 20 feet. Beyond such size there is a difficulty in making the pulley strong enough to stand a heavy load, and at the same time keeping its weight within bounds. It is very necessary that these pulleys should be as light as possible; if not, with quick winding they have a tendency to spin after the ropes cease running.

FIG. 279.

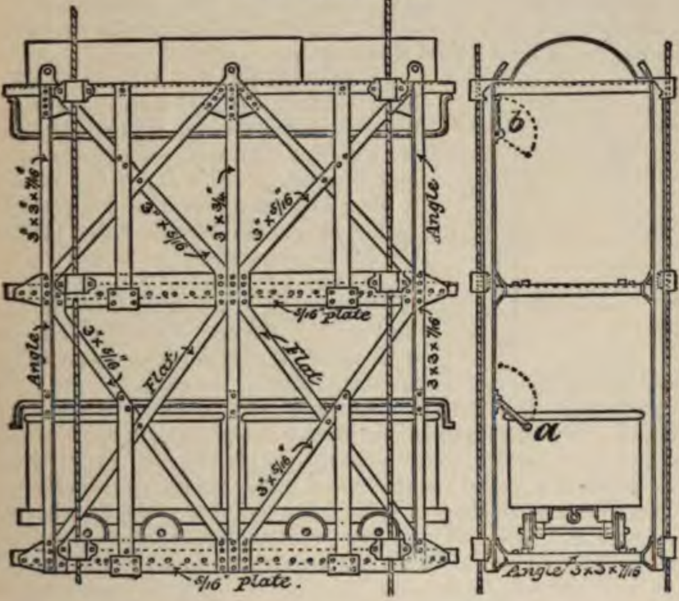


When flat ropes are used, the groove in the rim must be made perfectly flat, or the rope will be unduly strained. With round ropes, the bottom of the groove will be semicircular, of a sufficient size to suit the rope. It is essential that the throat should be made wide enough to allow the rope a certain amount of play, for, as each successive coil is wound on the drum, it is obvious that the position of the rope is constantly changing with respect to the vertical plane of the pulley.

SKIPS AND CAGES.—At one time the mineral was wound from the shaft in what were called skips, which were attached to the winding-rope through the medium of chains and swung loose in the shaft. The Mines Regulation Act, 1872, made it compulsory that guides should be adopted in all shafts over 50 yards deep; and at the present time practically all shafts are provided with guides, and the tubs placed in a framing, called a cage.

Shape and Construction.—The shape of the cage is determined by the size of the tubs, and the number on each deck. A common procedure in dealing with large quantities is to place two tubs, end to end, on each deck, and to have four decks. If the tubs are small ones, four may be placed on each deck. Then as to material. Everywhere cages are now constructed of steel. Each time a winding takes place, a certain useless dead weight has to be lifted, consisting of the weight of the tubs, the cage, and the rope hanging in the shaft, and it, therefore, becomes imperative, with deep shafts and heavy loads, to use material having the greatest strength and the least weight. Every second saved in the time of winding is of importance. Nothing is gained by having cages too heavy, while everything is lost. A heavy cage knocks itself to pieces, while the cost of a light one is so small, that the gain in output, which results from quicker winding, more than compensates for repairs and renewal. A good example of the modern colliery cage is that illustrated in Figs. 280 and 281. It holds two tubs on each deck, each weighing 7 cwt., carries 52 cwt. of coal, and weighs itself only 30 cwt., so that the useful load is 47.2 per cent. of the total weight. The horizontal frames are composed of angle steel, 3 in. by 3 in. by $\frac{7}{16}$ in., tied together by two vertical angle pieces and one flat strip on each side. A strengthening plate, 9 in. deep by $\frac{5}{16}$ in. thick, runs along each side of the horizontal frame, and the three uprights are bound together by diagonal struts. The author has employed a cage of exactly

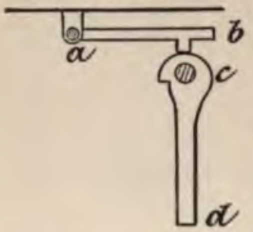
FIGS. 280 AND 281.



similar construction, only lighter, carrying 22 cwt. of coal and an 8 cwt. tub, the weight of the cage and bridle chains being only 11½ cwt.; the useful load is here 53.0 per cent. of the total load.

Means for Keeping Tubs on Cages.—When the tubs are placed on the cage some means have to be provided for keeping them there during the process of winding. This is done in a variety of ways, but by far the commonest, and perhaps the best, is to employ a bar of iron running along the side of the cage, each end of this bar being bent back at right angles. In its normal position it hangs as at *a* (Fig. 281), and locks the tubs, but on arriving at bank it is rotated, the ends describing the arc of a circle, shown by the dotted lines, and taking the position drawn at *b*, allowing the tubs to run off at one side, to be replaced by others, the bar being then pulled down again.

FIG. 282.



In some instances this bar, instead of being at the side of the cage, runs along the top of it, and when in its ordinary position the ends hang vertically under the influence of gravity. The bar (*a b*, Fig. 282) works about the centre, *a*, and is provided with a stop. On reaching the surface, the banksman pushes the hanging piece, *c d*, to the left hand, and a tooth in it catches the stop, *a b*, and holds it in a horizontal position. To release, the end *b* is lifted, and the catch drops to the vertical position, and so keeps the tubs in the cage.

ROPES.—Two forms of rope are used at collieries—flat and round. The advantage of the former is that as the rope is wound on the drum, each lap coils successively on the one below it, and the vertical plane of the drum and pulley therefore coincide. A certain amount of counter-balancing also takes place, as the drum varies in diameter. At the commencement of the wind it is small, but as the coils are wrapped on, it increases in diameter, until at the end its maximum size is attained. These considerations influenced at first, in a very marked degree, the choice of ropes for winding purposes, and flat ones were largely adopted. Experience has not, however, justified the selection, the above-named advantages being found to be more imaginary than real. Even with the deepest pits, it is possible to place the winding machinery at such a distance from the shaft that the angling, caused by a round rope coiling on the drum, is scarcely perceptible, or, at any rate, is not very objectionable, and it is also possible to perfectly counterbalance the weight of round ropes by several methods, which are described further on. Excepting on the Continent, flat ropes are becoming a thing of the past. They cost twice as much as round ones, and only wear about half as long.

Ropes are constructed of three materials—hemp, iron, and steel. In English collieries, hemp has never been used to any large extent, and at the present time, not at all. On the Continent hemp ropes are numerous, and iron or steel ones rare; aloe fibre is, however, employed instead of hemp. It is difficult to understand why this class of material is retained, for its strength is so small, that a very large and heavy rope has to be employed. The engineers state that its great advantage is the non-liability to breakage, owing to the perfect reliability and uniformity of construction, but statistics do not bear out this claim.

Wire Ropes.—In the early days, no doubt, some steel ropes did fail in an unaccountable manner, but at the present time their manufacture has reached a high degree of perfection, especially in England.

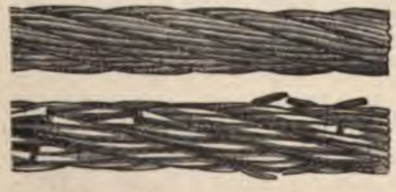
Wire ropes were first constructed of iron, but are now made almost entirely of steel. No advantage is gained by using the former material; it does not wear well, and its tensile strength is so small that heavy ropes are required. Most manufacturers supply steel in three qualities—Bessemer, crucible, and plough. The latter is about 50 per cent. stronger than the former, but only about 12½ per cent. stronger than crucible steel. Crucible steel ropes can be purchased in all ordinary sizes from £32 to £41 per ton, while plough steel ropes cost from £54 to £66. For all situations where a rope is *worn out* and not spoiled, the latter are worth the extra money. Every rope put to work should have a record kept of its performance, that is to say, the number of tons that it either hauls or winds. Statements are sometimes made that a rope has lasted so many years. Unless the number of tons is known, such an assertion is valueless, because a rope in another position might have lasted only half as long, and yet have dealt with more tonnage. On inclines, or places where a rope is subjected to severe shocks and strains, it is not advisable to use plough steel, because the rope may be broken and spoiled before it is anything like worn out, but for slow-moving rope haulage, or, especially winding, the highest priced ropes are the cheapest in the end; in the first place, owing to their great strength, a smaller weight is required, and in the second, their life is much longer.

Ropes usually stretch when first started, and probably get more brittle with work. They should be carefully manufactured, and carefully and thoroughly examined. The best signs of the limit of work, are the wearing and occasional breakage of the wires. The principal cause of failure is due to oxidation, especially with steel. Unless ropes are kept free from rust, they will never last, no matter what material is used in construction. How often oiling is required depends on the conditions of the working places. The grease required for such purpose should be rich in fat and quite free from acids, and, what is of the greatest importance, should not turn hard, or the outside wires will get well greased, while the inside goes rusty. A simple but effective rope-greasing apparatus consists of a cylindrical case made in two halves, and provided with two handles, which are grasped by the attendants, one on each side. Brushes are arranged in the top part and clean off the old grease, while the rope runs through a bath of oil held in a cup just below; the grease is thoroughly rubbed in by some loose felt, also saturated with grease, which is situated in the base of the cylinder.

The drums and pulleys should be as large as feasible, a good rule being that their diameter should never be less than a hundred times that of the rope. The angle that the rope makes with the pulley should be as small as possible. Ordinary ropes consist of six strands, of seven wires each, twisted round a hemp core; but for special cases where small drums have to be employed, the diameter of the wire is decreased, and more wires and strands used to make up the rope. Except for such purposes, no advantage is gained by this construction, as although the tensile strength of the wires is increased, they are apt to break after a little wear. After a thin wire has worn a little, only a small quantity of material remains, while the same amount of wear on a larger wire is scarcely perceptible.

For ropes with hemp cores, if the circumference in inches be squared, the product will practically be the weight in lbs. per fathom. In deciding on the size of rope required, the weight to be lifted is first determined. For a winding-rope such load must include the weight of cage, tubs, coal, bridle-chains, and the rope hanging in the shaft. Each manufacturer issues a card giving the breaking strain of different qualities of ropes, or if the particulars are forwarded, he will readily advise a suitable size. The breaking strain, however, is not the working load. For shaft work the safe load is taken at one-tenth the breaking strain, and for inclines one-seventh. In the former case, men have to travel on the rope, and for such reason a higher margin is allowed.

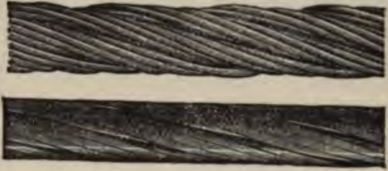
FIGS. 283 AND 284.



Ordinary Lay.—As ordinarily constructed (Fig. 283) the strands of a rope are laid in the *opposite* direction to the twist of the wires in each strand, with the result that the wear on the crown of the strand is great and the wires readily break there (Fig. 284).

Lang's Patent.—In England the first successful change from the old construction was introduced by Messrs. Cradock, in 1880. In Lang's patent, the wires are spun in the strands in the *same* direction as the strands are laid in the rope (Fig. 285). There is, therefore, a much larger surface exposed to friction. In working round drums, &c. the wires are bent obliquely, and thus the greatest amount of wear is obtained. Lang's rope wears out; it is only under the most exceptional circumstances that wires break. Fig. 286, from a photograph, illustrates the gradual reduction that takes place in the diameter. This construction has increased the life of the ropes at least 100 per cent., and no greater argument can be adduced in its favour than the fact that as soon as Messrs. Cradock abandoned their patent rights every manufacturer commenced making ropes of this construction. There seems, however, to be still some "unknown quantity," as the author's experience of Messrs. Cradock's ropes is that they give better results than those of other firms made on the same principles.

FIGS. 285 AND 286.



Locked Coil.—With the object of increasing the wearing surface, locked coil ropes were introduced in 1885. A series of coils of wire are spirally wound upon each other, all of which, or sometimes only the outer one, are composed of special section wires, which when closed together, interlock, and present a smooth uniform working surface. The rope in external appearance resembles a bar of iron, but is exceedingly flexible, and has little tendency to twist. At first, there must have been some defect in the manufacture, as the outside coils slipped on the inside ones and the ropes broke up soon. At present, their chief disadvantage is the impossibility of splicing and difficulty of capping. Recently, flattened stranded ropes have been introduced, and can be spliced with readiness, but have not been in use long enough to establish any data as to their economy or otherwise.

FIG. 287.

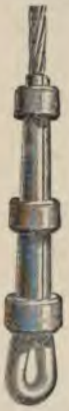
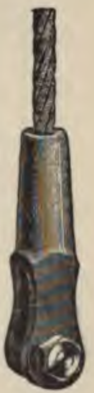


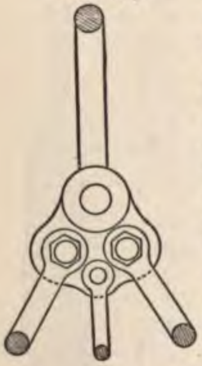
FIG. 288.



Attachment to Cage.—The end of the rope is connected to the cage chains through what is known as the capping, which exists in many different forms. The old plan was to employ two semicircular collars encircling the rope, these being prevented from slipping or drawing off by rivets, which passed both through the rope and capping. The driving in of these rivets necessarily injured the ropes; to remove this disadvantage, a capping with collars driven on (Fig. 287) was adopted. A better plan is to employ a conical socket (Fig. 288). In attaching this, the rope is first of all threaded through the thin end and drawn out a short distance beyond. The ends of the strands are opened, and bent back on themselves, part of each strand being cut away, and in every instance are secured with thin binding wire. The end of the rope is now conical, and is drawn into the socket. As an additional security, a conical wedge is often inserted in the place originally occupied by the hemp core. Except under abnormal conditions, it is impossible to draw the thick end of the rope through the small end of the socket, except by splitting it. If properly constructed of suitable material, such could scarcely happen, but for very heavy loads, collars are shrunk on. At the point where the rope leaves the capping the wires are subjected to a nipping action, and often break. It is, therefore, advisable that careful inspection should be made, and a plan is adopted at many collieries of re-capping ropes at regular intervals, whether they appear to require it or not. In wet shafts, the wires rust inside the capping, and such action cannot be detected. To prevent it, the capping is often run full of lead.

Cage Chains.—The cage is attached to the capping through the medium of chains, usually six in number, one at each corner, and one from each centre of the two longest sides. The two latter are often allowed to be slack, and only the corner ones kept taut. There appears no reason why such should be done, as if six chains are required, all should do a proportion of the work. It is argued, that the object of the central chains is to take the weight if anything happens to the corner ones, and, no doubt, it is a difficult matter to keep six chains of such a length that all take an equal bearing, but the difficulty is overcome by providing the two central ones with adjusting screws, which enable any slack to be readily taken up. These cage or bridle chains should be of the very best quality of iron obtainable, and should be regularly taken off every three or four months and annealed; so much depends on them, that no precaution should be neglected. As a rule, each pair of chains is connected to a larger link at the end furthest from the cage, and each of the three larger links are in turn connected to a still larger link, which is fastened to the capping by a bolt. With this method, if anything happens to the main link the cage is detached from the rope. The better plan, and common procedure in the North of England and on the Continent, is to connect the link joining each pair of chains to a compound plate, shown in Fig. 289.

FIG. 289.



The breaking strain of chain made from the best qualities of iron can be found by an easily remembered rule:—If W = breaking strain in tons, d = diameter in eighths of an inch: $W = \frac{d^2}{10}$. The safe working load for shafts should not be more than one-tenth of the breaking strain.

Method of Taking Off Strain.—When the cage is resting at the bottom of the shaft, and is suddenly lifted, the strain on the winding rope is much greater than that due to the load, especially if there is any slack chain. Messrs. Cradock have published a table showing the result of some tests, very carefully made by a dynamometer, from which it appears that the extra strain may amount to over twice the real load, as will be seen from the following extract:

	Tons.	Cwts.
Cage and four full tubs weighed by machine . .	5	1
„ lifted gently	5	3
„ „ with 3 inches of slack chain . . .	8	10
„ „ „ 6 „ „ „ . . .	10	10
„ „ „ 9 „ „ „ . . .	12	10

The extra strain has an injurious effect on the rope, and numerous devices have been proposed from time to time to reduce it. The author, in visiting Mariemont Colliery in Belgium, observed a simple but effective device, which he has since adopted at Lye Cross Pit. In addition to the ordinary bridle-chains, a central one, passing from the capping of the rope to the centre of the cage, is also employed (*a*, Fig. 290). It may be considered as

FIG. 290.

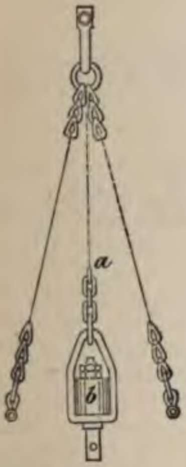
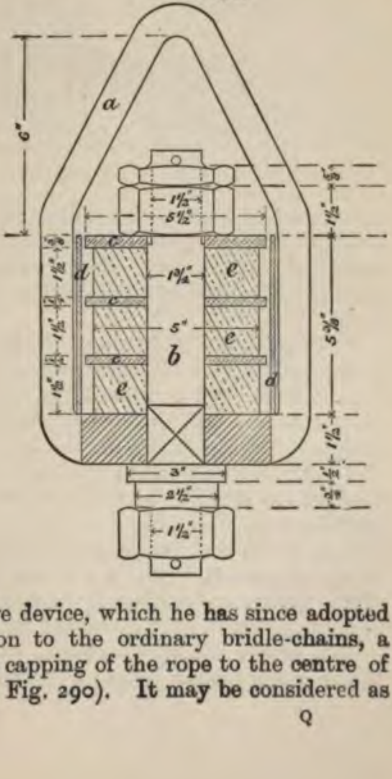
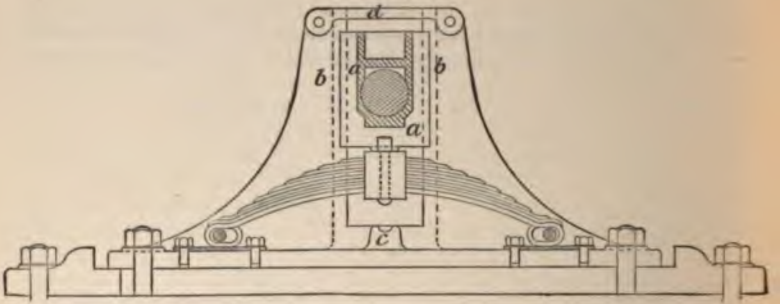


FIG. 291.



a prolongation of the winding rope, but is *shorter* than the vertical distance from the capping to the top of the cage. To it is attached an apparatus, *b*, shown enlarged in Fig. 291. The central bridle-chain is connected to a stirrup, *a*, while the pin, *b*, is attached to the cage. Threaded on this pin are alternate discs of sheet-iron, *c*, and india-rubber, *e*, kept in proper place by the nut and lock-nut at the top of the pin, *b*; both india-rubber and sheet-iron discs are enclosed in a cylindrical case, *d*, to protect them from dirt, &c. When the lift commences, the central chain, being shortest, does all the work, the stirrup, *a*, slides on the spindle, *b*, and compresses the india-rubber discs, until the central chain lengthens to such an extent that the corner chains come into operation and do their share of work. Instead of this arrangement, volute springs are sometimes employed, and have been used at Mariemont, but were abandoned through unreliability, as they often broke and caused mishap. The weight of such a rope-easing gear, including the central chain, two angle pieces across the top of the cage, and all the fittings caused by the addition, is only 71 lbs., and its cost is small.

FIG. 292.



In some cases india-rubber blocks have been placed beneath the pulley pedestals, but, being exposed to the weather, the blocks soon become hard and lose their elasticity. A superior plan is to place the pedestal on springs similar to those used in railway waggons. Fig. 292 shows such an arrangement at Bell End Pit. The pedestals, *a*, work in guides, *b*, and have a play of about 2 in. The guides compel the pulley to travel in a vertical plane and prevent it from canting. A stop, *c*, is provided underneath the spring to prevent it compressing too much, and a cross-bar, *d*, is placed over the top to prevent the carriage being sprung out of the guides under abnormal shocks. This arrangement is used in conjunction with the central chain-gear just described.

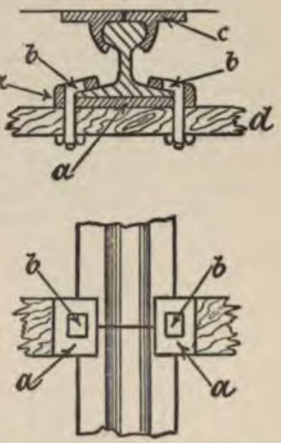
It is rather a difficult matter to estimate definitely the additional life of a rope caused by adopting such arrangements, but some good must result, and the cost of either or both of them is small.

GUIDES.—The cages are not allowed to swing free in the shaft, but are kept in the proper direction by guides, which may either be wood, iron rails, or wire ropes.

Wood guides are usually made of pitch-pine, are joined together in lengths, and are secured to cross baulks by screws. They are unsuited for quick winding, are costly to fix and keep in repair, but they are rigid, and their first cost is small. For deep shafts and heavy loads, the small advantage in cost is soon counterbalanced by the cost of the up-keep. With few exceptions, they are a thing of the past.

Rails.—To obtain the rigidity of wood and to avoid rapid wear, rail guides firmly attached to buntons have been substituted. It is obvious that the ordinary form of chair employed on railways cannot be used, as the head and neck of the rail have to be left clear, in order that the sliding attachment on the cage may pass freely along. As a rule, the flange of such rails is made broader than the ordinary construction, and is fitted into a chair, *a* (Figs. 293 and 294), and prevented from moving laterally by two pins, *b b*, the heads of which are bent round to grip the foot of the rail, and counter sunk in the chair to prevent the guide shoe, *c*, catching them. The two pins pass through the chair, *a*, and are bolted at the far end to the cross buntons of timber, *d*, carrying the whole structure. At Horloz, near Liége, rail guides are fastened together by fish-plates at the *back*, bolted to the rails; the buntons in this case are not placed at the joints.

FIGS. 293 AND 294.



Rail guides are not only expensive, but require a lot of attention. Mr. Ch. Demanet[*] gives the following statement of the cost, where the rails weighed 58 lbs. to the yd., were each 9 yds. long, and were fished and bolted to oak buntons set 5 ft. apart. In the walling, the buntons were set in cast-iron sockets; in the tubbing, iron circles of U section rested on the ribs, and these carried transverse girders, to which the rails were attached. A space of 0.078 in. was left open between the ends of the rails for expansion, and the bolt-holes in the rails and fish-plates were made oval in the usual way.

[*] For. Abs. N.E.I. xxxi. 28.

Cost where Shaft was tubbed.

	£	s.	d.
(a) *Circles.*—Cost of each circle complete, placed in pit, including all bolts and washers, and erecting	1	3	2
(b) *Rails.*—@ £5 14s. per ton, (4 yds. required for each yard of shaft)	0	11	10½
Fixing in shaft	0	1	5
(c) *Fish-plates*	0	0	9½
Total cost per yard	£1	17	3

Cost where Shaft was walled.

	£	s.	d.
(a) *Buntons.*—Oak buntons 6′ 10½″ × 6′ × 8″, with 8 bolts and washers, and fixing in shaft	0	11	7
Rails and fish-plates as above	0	14	1
Total cost per yard	£1	5	8

On the Continent, the common system of fixing rail guides is that due to Mr. Al. Briart, which consists in dividing the shafts by a single series of buntons of H steel girders, which at Mariemont are 14.96 feet long, 0.82 feet deep, and are placed 9.84 feet apart. The utmost care is exercised in getting these buntons in the same vertical plane, and previous to being fixed they are notched to receive the rails, which are each 19.66 feet long, thus giving a slight play between the joints. To secure the rails to the buntons two steel glands (*a*, Fig. 295) are fixed, one on each side of the rail, which they firmly grip, a bolt, *b*, passing from one gland to the other. To prevent any chance of movement, a block of cast-iron, *c*, through which the bolts pass, is placed between the rails, and is furnished with a slight projection, which lies in a corresponding groove rolled in the flange of the rail. At buntons where joints occur, two sets of these glands and blocks are fixed, one above and one below; but at the intermediate buntons only one set at the top of the girders is used.

FIG. 295.

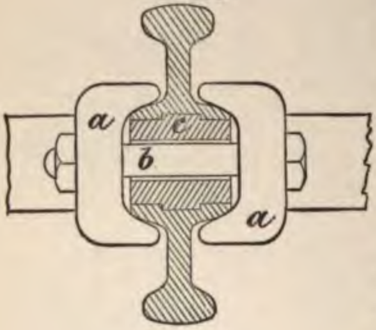
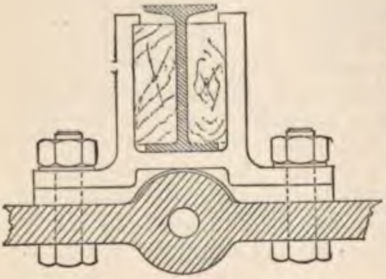


FIG. 296.



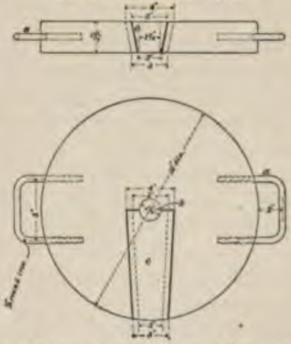
In passing through tubbing, the buntons are carried in shoes bolted to the internal flanges, the girders being wedged in position with wood keys (Fig. 296).

Wire Ropes.—In the majority of cases, rope guides are employed, but differ from ordinary wire ropes in the fact, that instead of consisting of a number of small wires twisted into strands, and then into a rope, each strand consists of only one wire, but such wire is of large diameter. At first guides were made like ordinary ropes, but when a little wear had taken place and a wire broke, the projecting piece was caught by the shoe of the cage, and the rope "stripped," causing frequent stoppages. As rope guides have only to sustain small weights, wire of high tensile strength is not required.

Rope guides are cheap in first cost (they can be bought for £16 a ton), are easily fixed, require no attention except oiling, and their wear is almost unlimited. They must, however, be kept taut by proper means. At their upper extremity they should be capped like a winding-rope, and connected to eye-bolts in the head-gear. At the bottom they should pass by the side of a bunton, be held there by a staple, and weights added to their lower end. Instead of weights, screws are sometimes used. In deep shafts expansion and contraction regularly take place in the guides owing to the variation in temperature, and the length alters considerably from a hot day in summer to a cold day in winter. If screws are used, the guides require constant attention if they are to be kept taut, whereas, if they are weighted, they are always tight, as the tension is always the same.

It is a difficult matter to say what weight should be applied to each rope, and for this reason it is not advisable that such weight should be in a solid block. The proper weight is a matter of experiment; it varies from 2 to 4 tons. In addition, one large weight is very awkward to deal with. A series of single weights, therefore, appears preferable, and are best constructed as shown in Figs. 297 and 298. Each one is provided with two handles, *a a*, has a hole through the centre, *b*, and a loose wedge-shaped piece, *c*, which when removed allows each weight to be slid on the rope without moving any of the others. This piece, *c*, is not only wedge-shaped in plan, but also in cross section, and cannot drop out of place when the weight is in a horizontal position. The blocks weigh about 165 lbs. each, and can be handled by two men.

FIGS. 297 AND 298.



Conductors between Cages.—The only objection urged against wire guides, is that the clearance between the cages has to be more than if a rigid conductor was employed. For deep shafts this is, no doubt, true, if the guides are connected to the cage on both sides; but a method is used which entirely removes the disadvantage, and allows the cages with wire conductors to be safely worked with as little clearance as if rail or wood guides were employed. In ordinary cases three conductors will be fixed to each cage; in the special method, two conductors only are fixed to each cage, both on one side of it, *but in between the cages, and unconnected to either of them*, two other ropes are suspended. These latter ropes are often flat ones, and at the point of meeting are lined with steel strips passing from one to the other, while the cages are lagged up on the inside. The result of the whole arrangement is, that from the top of the shaft to the bottom, the cages are on opposite sides of the central conductors, and cannot possibly catch each other when passing.

FIG. 299.

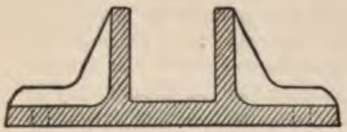
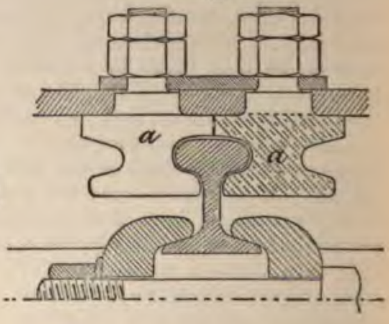


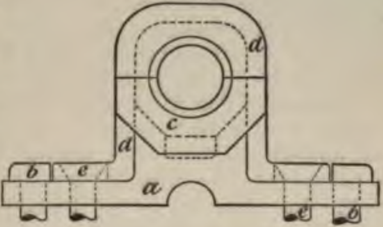
FIG. 300.



Guide Shoes.—Some connection has to be made between the cage and the guides, so that the former shall travel correctly along the latter. If the guides are of wood, the shoe need not encircle them, and the form shown in Fig. 299 is employed. With iron rail guides, which are also rigid, the common form of shoe has already been illustrated in Fig. 293, but with a view of reducing resistance, rolling has been substituted for sliding friction, and at Anzin Colliery, France, the guide shoe is composed of two wheels, one on each side of the rail guide (*a a*, Fig. 300), revolving on a pin bolted to the side of the cage.

For wire ropes, which are flexible, the guide shoe must go completely round them, or any oscillation would throw the slipper off the guide. A common mistake is to make the shoes very much stronger and heavier than necessity requires. If the guides are properly hung, and the centres of the shoes set to the correct gauge, very little strain is thrown on them, and only a comparatively weak connection is required. It is advisable that renewable bushes should be provided for the parts gripping the rope, as all the wear takes place there. A good form is shown in Fig. 301. It consists of a base plate, *a*, bolted to the cage by two pins, *b b*, and has cast-iron bushes, *c*, divided into halves, these being fixed to the base plate by a steel strap, *d*, which encircles them. This strap is kept in position by two pins, *e e*, also bolted to the sides of the cage. By taking out these two latter pins, the bushes can be changed whenever desired without removing the base plate. As an experiment, the author tried brass bushes, but the result was by no means satisfactory. The first cost was much more than that of cast-iron ones, and their life was considerably less. If the guides are kept well lubricated the wear is slight.

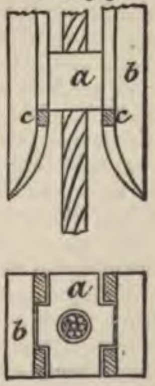
FIG. 301.



Guide Troughs.—While the cage is travelling in the shaft a small amount of oscillation is not objectionable, as there is seldom less than from 2 to 4 in. clearance at the corners, but when passing through the timber framing at the top, or at intermediate hanging-on places, where the clearance space is small, additional means have to be provided to prevent the cage from deviating from a definite line. With rigid guides nothing is necessary, but with wire ropes the general plan is to place a trough opposite each guide at the point where they pass through the frame. The usual construction is to rivet two strips of angle iron to a plate at the back; the angle pieces are belled out at the top and bottom ends of the trough, and the back plate is bent outwards to avoid any chance of the slipper receiving a blow when it enters the trough as it is gradually guided into the proper groove. The troughs are held in position by two bolts which pass through the timber framing.

Where the banking level is a considerable distance above the ground, it is by no means a rare occurrence, when storms prevail, for the guides to be blown out of the troughs, and if this happens during winding a serious accident may result. Mr. A. B. Southall has designed a simple appliance, which entirely gets over the difficulty. A sliding block, *a* (Figs. 302 and 303), with a projection on each

FIGS. 302 AND 303.



side, is placed in the guide trough, *b*, which is recessed to receive the projection. This block is free to move upwards, but is prevented from dropping completely out of the trough by a stop-plate, *c*, placed at the lower end. In its normal position it rests against this stop-plate, and the guide passes through a hole in the centre, and is always locked in its proper position in the trough. When the slipper of the cage reaches this block, it lifts it upwards, but on the descent of the cage the block, by the action of gravity, drops into its former position.

Engines.—For winding purposes a pair of engines, with the cranks set at right angles, is the only form admissible. There are, however, two ways of placing these engines, either vertical or horizontal. Vertical engines are becoming things of the past. In the first place the cost of foundations is great. The drum of a winding engine may weigh anything up to 80 tons, and if such a mass has to be placed 30 to 40 ft. above the ground, and revolved at a high velocity, the structure carrying it must be correspondingly large. Vertical engines were designed to reduce wear in the pistons, it being considered that if a large cylinder was placed horizontally, the lower half would wear very fast. For the same reason, with horizontal engines it was usual to employ back piston-rods, but both in this case and in the former one, the evil has been proved by experience to be more imaginary than real, and as a result, both vertical engines and back piston-rods are being abandoned. At Harris Navigation Colliery, inverted engines are applied at one pit—that is to say, the drum is placed below and the cylinders above. The cost of foundations is reduced, but it would appear that no real benefit results, as the second pair of engines at the same colliery are placed horizontally.

The design and strengths of the various parts is more a matter for the mechanical than the mining engineer. The stroke is usually made twice the diameter of the cylinder, and the connecting rod three times the length of the stroke. The valves, both steam and exhaust, should be of large proportions. In winding, everything is sacrificed to speed. The engine should be simple, easily handled, and, above all, over its work. On large engines, the double beat, or Cornish valve, has until recently been the one generally adopted, owing to the ease with which it is capable of being moved, but modern improvements in the design of equilibrium slide valves have largely brought such class into favour.

The proper size of engine to do a given amount of work may be easily found by applying a very elementary formula of mechanics, but simple as the problem is, the determination of the required size is often more a matter of guess-work than of reasoning. In moving a load, an engine has to do two things. Every one is aware that a greater expenditure of force is required to move a load than to keep that load in motion when once started. The greatest work that a winding engine has to do, is to get a given mass into a certain velocity uniformly accelerated from rest, and to raise the load the distance passed over during the time this velocity is being obtained. Mr. Robert Wilson [*] suggests a formula, based on such reasoning, which, if followed, will be found to be satisfactory.

W = the weight to be set in motion : one cage, coal, number of empty tubs on cage, one winding rope from pit-head gear to bottom, one rope from bank level to bottom.

v = greatest velocity obtained uniformly accelerated from rest.

g = gravity = 32.2.

t = time in seconds during which v is obtained.

L = unbalanced load on engine.

R = ratio of diameters of drum and crank circles.

P = average pressure of steam in the cylinders.

N = number of cylinders.

S = space passed over by crank pin during time t.

C = $\frac{2}{3}$; constant to reduce angular space passed through by crank, to the distance passed through by the piston during the time t.

A = area of one cylinder.

f = addition for friction, &c., of engines varying from 10 to 30 °/₀ of A.

B = area of cylinders with margin for friction allowed.

D = diameter of cylinder required.

1. Where the load is balanced :

$$A=\frac{\left\{\left(\frac{Wv^2}{2gt}\right)+\left(L\frac{vt}{2}\right)\right\}R.}{P.\ S.\ N.\ C.}$$

$$A+f=B,\ \text{and}\ D=\sqrt{\frac{B}{\cdot 7854}}$$

2. Where the load is unbalanced.

The symbols will retain their significance, and the formula will remain the same as before, with the addition of another term to allow for the variation of the lengths of the ascending and descending ropes. In this case :—

h_1 = reduced length of rope in t attached to ascending cage.

h_2 = increased length of rope in t attached to descending cage.

w = weight of rope per foot in lbs.

$$A=\frac{\left[\left(\frac{Wv^2}{2gt}\right)+\left\{\left(L\frac{vt}{2}\right)-\left(\frac{h_1w+h_2w}{2}\right)\right\}\right]R.}{P.\ S.\ N.\ C.}$$

eliminating gives

$$A=\frac{\left[\left(\frac{Wv^2}{2gt}\right)+\left\{\left(L\frac{vt}{2}\right)-hw\right\}\right]R.}{P.\ S.\ N.\ C.}$$

$$A+f=B,\ \text{and}\ D=\sqrt{\frac{B}{\cdot 7854}}$$

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[*] Ches. Inst. xi. 267.

To show how this formula is applied, perhaps the best way will be to work out an example, assuming that 1200 tons are to be raised from a depth of 420 yds. in 8 hours, that the tubs weigh 7 cwt. each, and carry 12 cwt. of coal, that four tubs are raised on each cage, which weighs 30 cwt., and that the pressure of steam will be 70 lbs., the diam. of drum 18 ft. and the stroke 5 ft.

1200 tons in 8 hrs. = 150 tons an hour, and as each journey carries 48 cwt., nearly sixty-three journeys have to be made in each hour, and each journey must not occupy more than 57 seconds. As numerous small stoppages always occur, it would be best to assume that winding and changing has to take place in 50 seconds. If changing is performed in 8 seconds, the actual time of winding will be 42 seconds, and, as the shaft is 1260 ft. deep, the average speed will be 30 ft. a second. The maximum velocity will be at least 40 ft. The time *t*, in which this velocity is obtained, may safely be taken as $\frac{1}{7}$th of the total time of winding = 6.

The rope should be of plough steel weighing $2\frac{1}{2}$ lbs. per foot. If the load is balanced $L = 48$ cwt. $= 5376$ lbs. If the head-gear is 60 ft. high, $W = 18,322$ lbs. In the time *t*, the drum will probably make three revolutions, therefore $S = 3 \times 5 \times 3.1416 = 47.13$. $R = 3.6$.

$$A = \frac{\left\{\left(\frac{18322 \times (40)^2}{2 \times 32.2 \times 6}\right) + \left(5376 \times \frac{40 \times 6}{2}\right)\right\} 3.6}{70 \times 47.13 \times 2 \times \frac{2}{3}} = 590.1$$

$$B = 590.1 + f \text{ (say } 15\,{}^{\circ}\!/\!_{\circ}) = 678.6$$

$$D = \sqrt{\frac{678.6}{.7854}} = 29.4, \text{ say 30 inches.}$$

Position of Engine House.—In nearly every case the direction of the inset governs the position of the winding engine, the drum shaft being generally at right angles to the axis of the inset and cages. The choice, therefore, appears to be limited to two positions, either A or B (Fig. 304). Such, however, is not the case; the cages may still be kept in the same line by placing the pulleys obliquely, shown by dotted lines, and, by doing so, the engine-house may be situated at, say, either C or C^1, or practically anywhere; indeed, by putting one pulley over the other, the engine may be placed at right angles, D, to the axis of the inset.

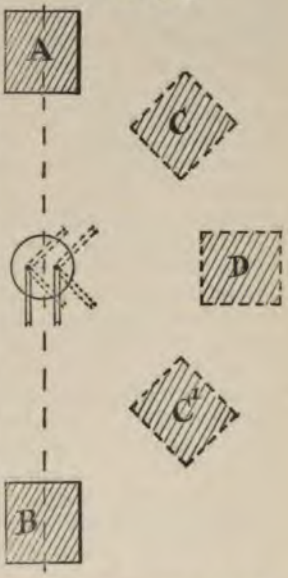
Drums.—The winding rope is coiled on a drum, which may be of various forms. The first division is produced by the type of rope adopted.

The ropes are flat ones and coil on themselves; the drum consists of a narrow cylinder of small diameter fitted with horns on each side. Its weight is small and its construction simple.

The other main division is caused by the employment of round ropes. It has been tried to make round ropes coil on themselves, and employ a drum similar to that used for a flat rope, but the experiment did not meet with success. Three types of drums for round ropes are in use: (1) The ordinary cylindrical form, parallel throughout; (2) The conical; (3) The spiral.

The parallel form is obviously the simplest, cheapest, and least liable to accident. Its only disadvantage is the side friction resulting from the angling of the rope. The successive coils lie side by side, and as they lap on the drum are constantly moving relatively to the centre line of the pulley. An attempt is made to equalise this strain, by placing the drum in such a position that at the commencement of a wind the rope is at the same distance on one side of the centre line as it is on the other side at the conclusion—that is to say, the centre line of the pulley coincides with the centre line of half the drum.

FIG. 304.



The result, however, is that at first the coils do not lie against each other, but have spaces between, as the rope tries to get into the same plane as the pulley, but after the central point is passed, the rope still tries to keep in the same plane as the pulley, and the successive coils not only lie very close against each other, but a grinding action is set up between them.

This disadvantage is removed in some cases by turning shallow grooves in the circumference of the drum for the rope to coil in. It then winds evenly and grinding is avoided. A far cheaper plan, and an equally satisfactory one, is to make the drum *slightly* conical, instead of cylindrical, a slope of 1 in 10 being sufficient. The tendency of the rope to get into the same plane as that of the pulley, is thereby counterbalanced by its disinclination to climb the slope, and each coil winds evenly against the other. With either system, and a cylindrical drum, it is impossible to avoid side friction altogether. What is done is to make the side friction of one lap equal to that of another, and not throw all the grinding action upon one or two coils.

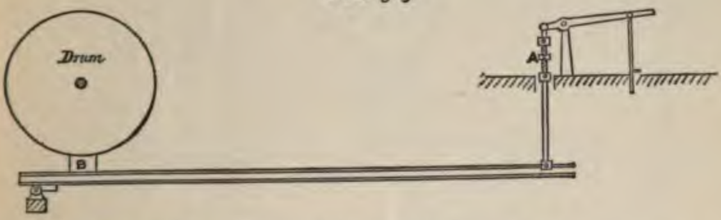
To obtain the advantage of counterbalancing, which is discussed further on, conical drums were designed—that is to say, the rope coils on a cone instead of a cylinder. The amount of counterbalancing that can be obtained is small, as the slope of the cone is limited by the fact that if it is made too great, the rope slips off. For this reason, their use has been abandoned. In their place spiral drums have been substituted, which consist of a combination of a cone and a cylinder. The cone is very steep, and on its side is arranged a spiral groove, usually made of semicircular iron troughs. The rope commences to coil at the small end of the spiral, and gradually ascends the cone, finally wrapping on the cylindrical part, the latter being added to reduce the width of the drum and the angling of the rope. As each groove has to be placed at such a distance from the one immediately above, that the rope going from the lower spiral misses the troughs of the upper one, a considerable amount of space is occupied, and unless several of the coils took place on a cylinder, angling would be very large, and, in addition, for any great depth, the size of the drum would be enormous.

Several objections may be urged against spiral drums: (*a*) As pointed out further on, counterbalancing is not perfect; (*b*) Their enormous weight and cost; (*c*) The disadvantage attending banking. The cage at the bottom of the shaft is attached to the rope coiling on the smaller diameter of the drum, whilst that at the surface is connected to the larger diameter. When the cages are moved to change the decks, the drum has to be turned sufficiently to wind up on its *smallest* diameter an amount of rope equal to the height of a deck, whilst, at the same time, the cage at the surface is lowered a considerably greater distance, because the rope to which it is attached is coiled on the *larger* diameter of the drum. After the engineman has put the bottom cage in position, he has to lift up the top cage again to discharge its contents, the result being that time is lost in banking.

Brakes.—An efficient brake on a winding engine is an absolute necessity. In cases of emergency, very powerful ones are required, and to meet the case the brake-strap is connected through a lever to the piston-rod of a small engine, into which steam can be admitted. Such an appliance acts on the "all or none" principle; full power has either to be exerted or not. If steam be admitted to the cylinder, the power applied to the brake is due to the area of the piston multiplied by the pressure, and as neither the steam pressure nor the piston area can be varied, the power exerted is always constant. Immediately steam enters the piston such power is applied to the brake-strap, the result being that when a steam-brake is thrown into action the machinery is subjected to very severe shocks, and consequently such appliances are only used in cases of emergency. As a rule, winding engines are provided with two brakes, one applied by the engineman's foot, and the other by steam, the latter only being used on rare occasions. Several devices have been designed to increase the power and leverage of foot brakes, and to do away with those of steam.

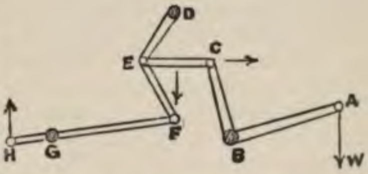
Burn's Brake.—The brake-strap does not encircle the drum, but consists of a block of wood (B, Fig. 305), about 24 in. long by 6 in. broad, in which a series of holes are bored and filled with sand. This block of wood is placed at one end of a long lever, the other end being moved up and down by a rod connected to the arm of another lever controlled by the engineman. The block being small in area, and fitted to the rim of the drum, only requires a very small movement to free itself, and the length of the lower lever being nearly equal to the length of the engines, it follows that a large amount of power can be applied. At Bickershaw Colliery, Lancashire, the leverage is about 200 to 1, and as there are two blocks on each drum the power exerted by the engineman is multiplied to a great extent. The action of the sand in the holes is to keep the brake rim free from grease. By the aid of an adjusting screw, A, the brake can be tightened in a few minutes and any wear taken up in the blocks, which are usually renewed about every four months.

FIG. 305.



Tyldesley Colliery.—A pair of 32 in. cylinder engines are here fitted with a powerful strap-brake, moved by a toggle-joint lever. The engineman exerts pressure through his foot-treadle in the direction of the arrow W (Fig. 306), pulls down the bell crank lever, A B C, moves the toggle-joint, D E F, and gives motion to the lever, F G H, working about the centre, G, the end, H, being attached to the strap going half round the brake-ring on the drum. The direction of motion in each part is shown by the arrows, and as the engineman puts on the brake, the toggle-joint, D E F, forms a straight line. At the instant this takes place the pressure exerted becomes infinitely large. B, D and G are the only fixed points.

FIG. 306.



Pasfield's Brake.—To obtain the power of a steam-brake, and yet remove the difficulties previously referred to, Mr. T. Pasfield* has designed a special valve and gearing (Fig. 307), which allows any variation of power to be applied, as the pressure of steam in the brake-cylinder is made to increase and decrease in proportion to the amount of force exerted by the engineman on the controlling treadle. The passage, *l*, leads into the cylinder of the steam-brake, which is fitted with a piston and piston-rod, the latter being connected by a link to the lever applying the brake. Steam is admitted on one side of the piston only, and enters and leaves the cylinder by the same passage. The valve-box, *a*, is fitted with two valves, *b* and *c*, both connected by gearing to the lever to which the foot-treadle, *f*, is attached, and controlled by the link, *e*. The valve, *b*, which admits steam through the passage, *g*, is kept closed by a spring, *d*, which just balances it against the steam in the boiler. The relief valve, *c*, unless the brake is in action, is in equilibrium, free to open or shut.

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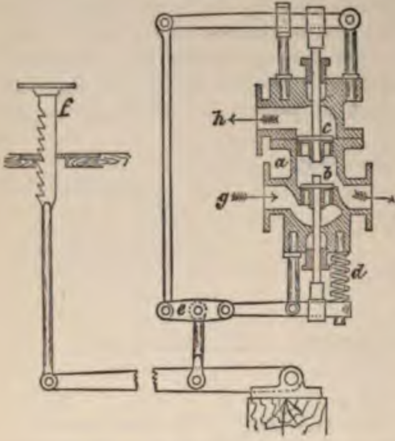
* So. Staff. Inst. ii. 112.

FIG. 307.



When the treadle is pressed down, the steam-valve is relieved of some of the pressure which keeps it closed, and steam enters the cylinder until its pressure is sufficient to again close the valve against the force exerted by the treadle, so that the greater the force exerted on the treadle, the greater the pressure must the steam reach before it closes the steam-valve. At the same time, as the treadle relieves the steam-valve of some of the spring pressure which tends to close it, it brings an equal force to bear on the relief-valve, *c*, to keep it closed; any increase of steam pressure in the cylinder beyond that intended at once escapes through the relief-valve. Thus, if the force exerted by the treadle to relieve the steam-valve, is to the extent of what amounts to one or two lbs. per sq. in., the steam-valve admits steam into the cylinder until the pressure there is one or two lbs. per sq. in., as the case may be, and then closes. The treadle at the same time exerts sufficient force to keep the relief-valve closed until the steam in the cylinder has reached the one or two lbs. pressure, and then allows anything beyond that to escape.

Counterbalancing.—With an ordinary cylindrical drum, unless some means are taken to counterbalance the weight of the rope hanging in the shaft, the engine is subjected to an enormous variation in the load, especially in deep shafts. If

w = weight of cage and empty tubs = 6270 lbs.
c = weight of coal = 4480 lbs.
r = weight of rope hanging down pit = 6000 lbs.

At the commencement, when the empty cage is at the top of the pit, the weight to be lifted will be:

$$w+c+r-w \text{ or } 10{,}480 \text{ lbs.}$$

In the centre of the run, half r would have been added to the descending load and subtracted from the ascending one; the weight on the engine is, therefore:

$$\left(w+c+r+\frac{r}{2}\right)-\left(w+\frac{r}{2}\right) \text{ or } 4480 \text{ lbs.}$$

At the end of the wind all the rope is acting in favour of the descending cage, and the weight on the engine becomes:

$$(w+c)-(w+r) \text{ or } -1520 \text{ lbs.}$$

During the complete operation the load varies from 10,480 lbs. against the engine to 1520 lbs. in favour of it. At the commencement of winding the engine wastes a great deal of energy in setting this mass into motion, and as speed is the main object, the engineman cannot cut off steam when most desirable, but must go on, and finally has to reverse the engines in order to bring them to rest. An enormous amount of energy is therefore lost in the latter part of the run, and such loss obviously increases with the depth of the pit.

Supposing, now, that by one of the methods of counter-balancing, the weight of the rope hanging down the shaft was balanced. If this new factor be denoted by r', the weight to be lifted at the commencement of the run will be:

$$(w+c+r)-(w+r') \text{ or } 4480 \text{ lbs.}$$

in the centre of the wind it will be:

$$\left(w+c+\frac{r}{2}+\frac{r'}{2}\right)-\left(w+\frac{r}{2}+\frac{r'}{2}\right) \text{ or } 4480 \text{ lbs.}$$

and finally

$$(w+c+r')-(w+r) \text{ or } 4480 \text{ lbs.}$$

The weight thus not only remains constant, but is considerably smaller at the beginning than in the other case. This reasoning will be clearly understood if it is remembered that for every decrement in r, an equal increment of r' is added, and as these two forces are equal and opposite at the beginning, they will necessarily be so at the conclusion.

Having thus proved the great advantage of counterbalancing, the means by which such is secured may now be considered.

Tapering Ropes.—A tapering rope enables winding to take place from greater depths than is possible with ropes of uniform section; the theory of taper ropes is to obtain uniform strength throughout, thinner at the cage end where the weight is least, and thicker at the drum end where it is greatest. Their thickness is such that the section at any part is capable of safely bearing the load on it at such point. With tapering ropes, a smaller initial dead weight is thrown on the engine, as their section at the largest point will be less than that of a rope of uniform section throughout, because a smaller weight has to be supported. The difference between the initial and final load is also smaller, but it increases more rapidly, because the larger diameter is wound on the drum in the ascending portion, while in the descending portion the larger section is being unwound. These ropes cost more than ordinary ones, and owing to the difficulty of manufacture cannot be made so perfect.

Flat Ropes.—This means of winding allows of a certain equalisation, for the radius of the coil of the ascending rope continues to increase, while that of the descending rope diminishes; consequently, as the resistance decreases in the ascending load, the leverage increases, and as the power increases in the other, the leverage diminishes. The variation in the leverage is a constant quantity, and is equal to the thickness of the rope. If the diameter of the drum be made small enough at the commencement, a remarkable uniformity in the load may be obtained, the only objection being the use of flat ropes.

Conical and Spiral Drums.—Results analogous to the preceding may be obtained by using round ropes coiling on conical drums. They may be either smooth, the successive coils lying side by side, or may be provided with a spiral groove. If a conical drum was constructed to give perfect equalisation, the sides would be so steep that the rope would slip off. For such reason scroll drums were designed, which are open to the objections already stated. In addition, the load is seldom perfectly counterbalanced. To obtain satisfactory wear from a round rope, it must be coiled on a drum of large diameter. Such condition limits the size of the smaller diameter, which is usually made so large that if the final diameter was of the proper dimensions to give perfect counterbalancing, the size of the drum would be enormous. For this reason, and to prevent the great lateral displacement of the winding rope from the centre line of pulley, owing to their necessarily large width, such drums are usually made for several coils to take place on the spiral, and the remainder on the flat.

Tail Rope beneath Cages.—With cylindrical drums, perfect counterbalancing can be secured by several methods, but all have given way to the endless rope system, which is preferable to all others if the shaft is free from cross-timbers. It consists of placing beneath the cages a tail rope, equal in diameter to the winding rope, and after conveying this down the pit into the sump, where it forms a loop, it is returned and attached beneath the other cage. When first introduced, it was considered that a pulley must be placed in the sump for the tail rope to pass round, such pulley remaining stationary under ordinary conditions, but free to move between guides and be lifted out of its bearings in case of accidents. In the majority of cases no pulley whatever is used. All that has to be done to keep the tail rope from twisting, is to fix two beams side by side across the pit in the sump, between which the tail rope passes, and another one below put across in the opposite direction, the latter passing through the loop in the rope.

It is perhaps preferable to use a guide pulley in the sump, as old winding ropes can then be used, otherwise a special rope has to be employed, as old winding ropes are not sufficiently flexible. The balance rope is connected to the bottom of the cage by an ordinary capping and bolt passing through a cross-bearer.

By this system perfect counterbalancing is obtained, as a factor is introduced equal and opposite to the winding rope, and gives equality at the beginning and the end. The one solitary objection urged against it, is that a greater weight is put on a tender part of the winding rope—viz., the capping, but if properly constructed and put on, the capping is quite as strong as the winding rope itself.

*Meinicke's System.**—A balance rope is employed in this method, but instead of attaching it beneath the cage it is connected to two auxiliary ropes, which may either be coiled on the same drum as the winding rope, or on auxiliary ones. The auxiliary rope passes over separate pulleys on the head-gear, and the balance rope is equal to the weight of both the winding and auxiliary ropes. Perfect counterbalancing results, and no additional weight is thrown on the capping of the winding rope. This, in conjunction with the fact that the balance rope may be led into any position in the shaft and boxed off, are the advantages, but as it is much more complicated than a tail rope beneath the cages, the latter seems preferable.

Expansion.—For economical working steam must be used expansively. With a continuously running engine there is no difficulty in doing so, but in the case of an intermittently running engine, working under the conditions which exist in winding, the problem is not so easy. As before remarked, everything is sacrificed to speed. It is essential that the engine should start quickly, should travel at a high velocity, and be quickly brought to rest; it is also essential that the engineman should be capable of putting either full steam on or against the engine, whenever required, and, above all, the machine should be simple. Under these conditions, regular expansion is quite out of the question. Of late years several most ingenious automatic variable expansion gears have been designed, which give satisfactory results. They are so arranged that at the beginning of a wind the engine takes full steam, and they only come into operation when the machinery has attained its maximum speed. The general type consist of "trip gears," that is to say, by some arrangement the valve is made to trip off the lifting lever, and close before the completion of the stroke.

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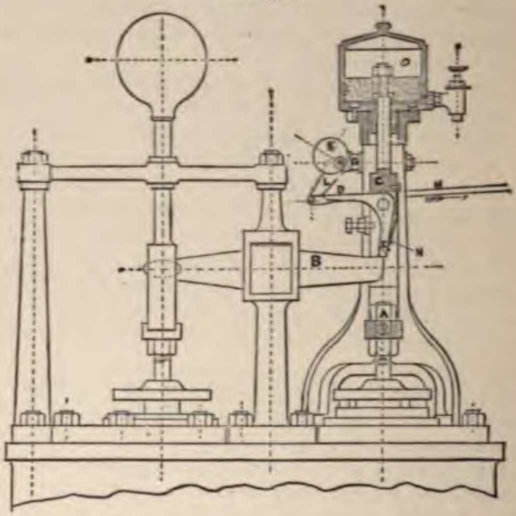
* *On Counterbalancing the Weight of Winding Ropes.* C. Meinicke. Ches. Inst. xiii. 336.

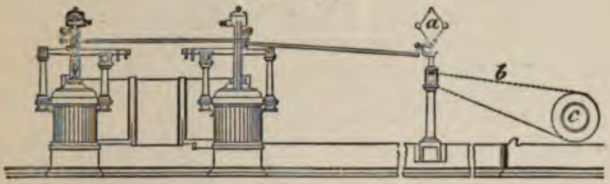
FIG. 308.



Musgrave Gear.—In Fig. 308, A is the spindle of an ordinary Cornish valve fitted with a dash-pot, O, at its upper end. With ordinary gear, the valve would be lifted by the lever B catching the projection C, but here a bell crank lever, D E, capable of turning about the centre, F, is interposed between the two pieces. Fastened to the upper end of the frame carrying the valve is a pin, G, and spindle, H, on which is keyed an eccentric, K. By means of the link, L, and the rod, M, a rotary motion can be given to the eccentric about its axis, H. At the beginning of a wind, the lever B (moved by the eccentrics of the engine in the ordinary manner) raises the valve through the bell crank, the spindles rising and falling with the lifter, as if no expansion gear was present. As speed increases, the rod, M, which is in connection with the governor, is moved in the direction shown by the arrow, turns round the eccentric, K, and depresses the end, D, of the bell crank. The lifter, B, then trips off the other end, E, of the bell crank, and allows the valve to close suddenly, any injurious shock being prevented by the dash-pot, O. The lifter, B, continues its upward journey without the valve, and on its return, the spring, N, pushes the bell crank into gear again. Fig. 309 shows the attachment of the gear to the engines. It is worked by a dead weight governor, *a*, driven by a strap, *b*, from the drum shaft, *c*.

In the case of a new installation, it is only necessary that the maximum speed at which the engines are to run shall be determined, and then by a proper relation between the pulley on the drum shaft, and the pulley on the governor, the point of cut-off can be readily fixed. This gear has been applied in numerous instances to winding engines, and the author has inspected its working on several occasions. At Tyldesley Colliery, Lancashire, the drum makes twenty revolutions, and a cut-off of $\frac{1}{8}$th commences at the fourth revolution. The gear does not come into operation until the maximum speed is obtained, and is thrown out of action by the governor towards the end of the wind, when speed falls. Its advantages are, that it has no complicated parts, is out of the engineman's way, and comes in and goes out of action without interfering with any of the parts handled by him, and, at the same time, allows full pressure of steam at the beginning and end of a wind, or at any other desired point during the ascent or descent of the cage; indeed, so far as the engineman is concerned, he is in just the same condition as if the gear were absent.

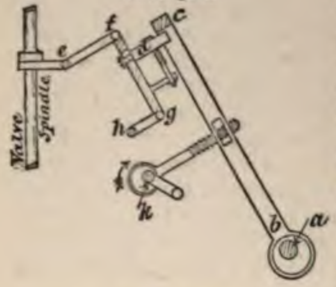
FIG. 309.



Grange Gear.—A gear is applied by the Grange Iron Co., which is similar both in principle and action to the one just described, and gives the same results. The only difference is in the arrangement of the parts. The lifter raises the valve through a curved rocking lever, under one end of which a sliding wedge is either pushed or withdrawn by a combination of levers moved by a governor. When the wedge is pushed under one end of the rocking lever (which takes place when the maximum speed is obtained), the lifter drops off the other end, and allows the valve to close at some intermediate point in the length of the stroke.

Sulzer Gear.—This arrangement has been applied to many engines on the Continent, and is most ingenious, although rather complicated. Fig. 310 is a diagrammatic sketch. The shaft, *a*, is driven by bevel gearing from the crank shaft, and revolves at the same speed. On it are keyed two eccentrics, only one, that working the steam valve, being shown in the sketch. By the revolution of the spindle, *a*, a motion to and fro in the direction of its length is given to the eccentric rod, *b c*. As this falls, it catches a projection, *d*, on the bell crank lever, *e f g h*, the fixed points of which are *e* and *h*, and the valve spindle is lifted. On a second shaft, *k*, is fixed an eccentric, which can be rotated by the governor in the direction indicated by the arrow. The rod of this eccentric is connected by a screw to *b c*. In ordinary working, the apparatus stands as shown in the sketch, and the valve is regularly closed and opened. When speed increases, the spindle, *k*, and its eccentric is rotated, and the bar, *b c*, pushed outward, with the result that the projection *c* trips off *d*, and expansion results.

FIG. 310.



Condensation.—Expansion to obtain the best results must be in combination with condensation, except where very high pressures are used. Unless condensation is employed the ratio of expansion can only be small, because the exhaust steam must have a pressure greater than the atmosphere. No satisfactory solution of the problem was obtained owing to the complication resulting, until the idea of using independent condensers was applied.

An independent condenser, as its name implies, is not fixed to, or moved by, the engine or engines whose steam it condenses, but is worked entirely by an engine of its own. To be a success, it should take steam from several engines, and run continuously. With it a constant vacuum is always retained. Many such appliances are in use, but it can scarcely be said that any are working perfectly satisfactorily, although many are giving good results. The chief difficulty seems to be to deal with the enormous volume of steam which comes from the winding engine at intermittent times. Winding engines are necessarily large, and run rapidly, so that when they are moving, especially if expansion is not used, the volume of steam discharged is very large, far more so than is general with continuously running engines. The condenser, therefore, has a difficulty in dealing with these sudden rushes. Another point is, that either a large quantity of water must be available, or some means introduced for cooling it. At Anzin Colliery the hot water from the condenser is cooled by being pumped to the top of a wooden frame and then allowed to fall through the air. A series of horizontal trays composed of brushwood are arranged beneath each other, and the water in falling from one to the other is split up into small drops, thereby largely increasing the cooling surface.

An instance of the work such an apparatus may do is supplied by an independent condenser and air-pump at Bickershaw Colliery, which is kept continuously working by a subsidiary engine. It takes steam from two pairs of hauling engines, having 16 in. cyl. by 3 ft. stroke, from a fan engine with 20 in. cyl. by 5 ft. stroke, and from a pair of 30 in. cyl. by 6 ft. stroke winding engines, and maintains a constant vacuum of 10 lbs.

Compound Engines.—Most economical results are obtained by what is known as compounding engines—that is to say, the engine is supplied with a high and a low pressure cylinder, and expansion takes place in each. The steam from the high pressure cylinder passes into the low pressure one. The object of using two cylinders is to obtain a higher degree of expansion than could take place in a single cylinder, with good results, as the difference between the initial and final temperature of the steam would be too great. A pair of compound engines would, therefore, contain four cylinders, and as simplicity is essential in winding machinery, such type has never met with favour.

Quite recently, however, it has been suggested that winding engines should be constructed in pairs as before, but instead of both cylinders being high pressure ones, one should be high pressure and the other low pressure, steam passing from the former into the latter. This is the type known as the twin compound, but the difficulty encountered with it was that sometimes it could not be got to start. Such failing was fatal to any application for winding purposes, as engines of such description are practically doing nothing else but starting and stopping. The first solution of the question was obtained by Mr. Wm. Galloway at Llanbradach Colliery.* Successful working followed on the introduction of a reducing valve between the steam pipe leading from the boiler to the high pressure cylinder and the pipe connecting the high and low pressure cylinders, regulated in such a manner as to maintain the pressure in the intermediate pipe, *when the engine was not at work*, as nearly as possible at the same average as the steam in that passage would naturally assume when the engine was working. In order to limit the quantity of steam passing through the reducing valve to the smallest quantity necessary to accomplish the object in view, a screw stop-valve was introduced in the pipe connecting the reducing valve with the high pressure steam pipe, and a steam pressure gauge on the intermediate pipe itself, for the purpose of enabling the reducing valve to be properly regulated.

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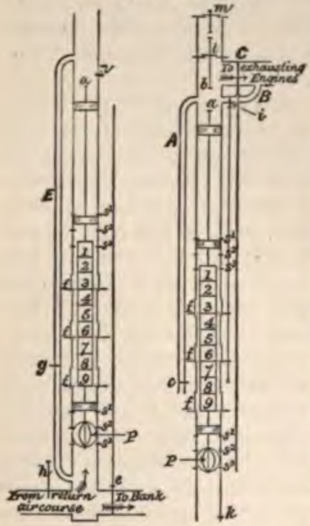
* So. Wales. Inst. xvi. 111.

Special Methods.—*Blanchet's Pneumatic System.**—The employment of round ropes is limited to a certain depth, as a point is reached beyond which they will not support their own weight. Taper ropes have theoretically no such limit, but practically they have, owing to the method of construction. To dispense with ropes altogether, Mr. Blanchet successfully applied at Epinac, France, the principle of the pneumatic tube.

The Hottinguer shaft was intended to reach 1100 yds., but, unfortunately, after attaining 711 yds. no workable coal was found, and, although the pneumatic system has been used for winding on a small scale, it was never carried out in its entirety; but sufficient experience was gained to prove that the idea could be a practical success. At the same time, the results did not show that it was superior in economy to the system of employing ropes, if counterbalancing be adopted. The expense of the installation was enormous. One tube 63 inches diam. and about $\frac{5}{16}$ in. thick was placed in the shaft. It was made up in about 20 ft. lengths riveted together with butt-joints and counter-sunk rivets. At first, it was thought that the tube would have to be bored, but such was found to be unnecessary, although each length was hammered to a perfectly cylindrical form upon a mandril. A diagrammatic representation of the scheme is given in Figs. 311 and 312, the former showing the cage at the bottom of the shaft, and the latter at bank.

FIGS. 311 AND 312.



The piston is made in two parts, one at the top of the cage and the other at the bottom, while the former is subdivided into two portions, placed at such a distance apart that in passing the doors through which the tubs are changed, one of them shall always be in an uncut position of the tube; this ensures the pressure remaining constant when the piston passes the doors. The lower part of the piston below the cage carries a parachute, *p*. The cage holds 9 tubs, one above the other; the load of coal carried is nearly 5 tons; and the total weight of the piston, cage, tubs, and coal is about 12 tons.

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* *Tube atmospheric du puits Hottinguer.* Z. Blanchet. Soc. Ind. Min. (2° Série), iv. 557 and vii. 273; T. W. Bunning, N. E. I. xxiii. 81. *Pneumatic Hoisting.* H. A. Wheeler. Amer. Inst. M.E. xix. 107.

When the air is exhausted above the piston, the latter commences to ascend, while for descent, exhaustion is stopped, its connection with the exhaust engine severed by means of doors at C, and air allowed to pass upon the top of the piston through the regulator, *c*. To remove the tubs from the cage three double doors, *f*, are provided in the tube, both at the top and the bottom, these corresponding to three levels of the heapstead. Three movements of the cage take place to change the nine tubs, and to keep it steady while such is proceeding, three double sets of stops, s^1 s^2 s^3, are introduced, and can be thrust into the tube or withdrawn by means of one lever. When the cage is confined between stops s^3 of the two sets, decks 1, 4, and 7 can be handled, while if the cage be confined by stops s^1 of each set, tubs 3, 6, and 9 are discharged

At the bottom of the shaft, the equilibrium pipe, E, goes from the bottom of the tube to a point sufficiently high to be above the piston during the whole time the tubs are being changed. When the cock, *g*, in this pipe is closed, the pressure of air on the bottom keeps the piston up against the top stops, and when the cock is opened, and the main inlet and outlet valves, *h* and *e*, shut, the air below is rarified, and the cage falls on to the bottom stops. At the pit top, the two pipes, A and B, are provided with stopcocks, *c* and *i*; the first is in connection with the atmosphere, to allow the cage to descend, while the latter is in connection with the exhausting engines, and is used to move the cage if required while banking is being performed.

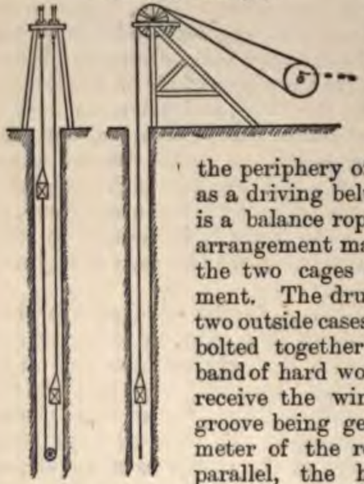
When the cage ascends, the doors, *f*, *f* and *e*, are shut, but when it arrives at the top, it is made to stop, first, by automatically shutting at *k* the connection with the exhausting engine at C, secondly, by moving the valve *l*, and admitting some air from the atmosphere, while if the ascent still continues, the valve *n* is lifted and the tube opened to the atmosphere. To avoid all shock when opening these valves, the top part of the piston carries a spring buffer, *a*. In the descent, when the cage arrives near the point where it has to stop, it automatically closes the escape valve at *n*.

The apparatus also serves to ventilate the mine. During the descent of the piston, the valve *h* is shut and *e* opened, and all the air contained in the tube is forced to bank, but during the ascent of the piston the valve *e* is shut and *h* opened, so that an amount of air equal to the contents of the tube is exhausted from the mine to be discharged into the atmosphere when the piston descends.

Koepe System.—In its lightest form a drum requires a large amount of energy to set it in motion, and an equal amount to stop it. In addition, for deep shafts the angling of the rope with the pulley is not only a disadvantage and a possible cause of accident, but a source of wear. To reduce this angling, and yet keep the drum relatively small in diameter and in width, the ascending rope is sometimes arranged to coil on the space from which the descending rope has been uncoiled. This is not often employed. It is inconvenient when repairs have to be made in the shaft and only one rope used; in ordinary cases the second rope is coiled on the drum, here it cannot be, as there is only space for one. In addition, the wear on the laggings is also great, and the centre part of the drum is soon cut into a deep groove.

To remove the objection to the weight, &c., of large drums, Mr. Fredk. Koepe designed the system where they are dispensed with altogether. The first application was made at Hanover Colliery, in Westphalia, and may briefly be said to consist in the substitution of a single grooved pulley in place of the ordinary drum. The winding rope passes from one cage over its head-gear pulley, round the "drum," and, after passing over the other head-gear pulley, is connected with the second cage (Figs. 313 and 314). The winding rope simply encircles about half the periphery of the drum, in the same manner as a driving belt on an ordinary pulley. There is a balance rope beneath the cages, so that the arrangement may be likened to an endless rope, the two cages being simply points of attachment. The drum pulley usually consists of the two outside cases of an ordinary cylindrical drum, bolted together and securing between them a band of hard wood in which a groove is made to receive the winding rope, the depth of this groove being generally equal to twice the diameter of the rope. Instead of being placed parallel, the head-gear pulleys are angled towards each other, with the object of reducing side friction.

FIGS. 313 AND 314.



The system has been in successful operation since 1877, and results show that the single winding rope lasts more than twice as long as the two ropes formerly adopted. Experiments made have determined that with a rope passing only one-half-turn round the driving pulley, the co-efficient of adhesion between steel ropes and wood rim is in practice 30 per cent., which would admit of an excess of 105 cwt. being placed on the present ascending load at Hanover Colliery before any slip can occur. The first application of this system in England was at Bestwood Colliery, Nottingham,* but after seven years' working it was abandoned (in

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* Ches. Inst. xi. 267.

1890) owing to the slip which took place when the winding ropes were oiled. At this colliery such slip was most objectionable, because winding took place at an up-cast shaft which was cased in all round. The engineman could not see his cages, but had to rely entirely on the indicator. On the other hand, at Sneyd Colliery, North Staffordshire, where the second application of this system in this country was put down, its working has been, and is, most satisfactory.

The merits and demerits of the system are fully explained in an elaborate inquiry by Mr. L. Trasenster,* and later particulars of the results obtained at Hanover Colliery are given by Messrs. Mahlet, de Gournay, and Suisse.†

When the cages reach the landing-place and rest on the stops, the weight is removed from the rope, and sufficient adhesive power does not exist on the rim of the motive pulley to enable the load to be re-started. This can be guarded against, either by dispensing with stops at the top, as is done at Sneyd Colliery, or by continuing the rope past the cages by means of cross-heads, above and below each cage, connected together by cross-pieces passing outside; the bridle chains are hung from the top cross-head, and when the cage rests on the stops the weight of the winding and tail rope still remains on the motive pulley. This was the arrangement used at Bestwood.

The great objection to the Koepe system, and the cause of its abandonment in a few instances, is the probability that if one rope broke both cages would be precipitated to the bottom. In Germany a brake block has been placed over the pulley, which, in case of the rope breaking, is automatically wedged against the pulley, and prevents the rope from slipping.

A recent installation in Belgium entirely removes this objection. Instead of one rope, two are employed. The drum has two grooves, and there are four head-gear pulleys. Each rope passes from one cage, over its head-gear pulley, round one groove in the drum, over the other head-gear pulley, and back to the other cage. Each rope passes half round the drum—in fact, the arrangement simply consists of duplicating the Koepe system. The only difference is in the attachment of the ropes to the cage. It is obvious that it would be a very difficult matter to keep both ropes exactly of the same length, while, if they varied, and one became longer than the other, the shorter rope would have all the weight, and the longer one would in all probability be thrown out of the groove on the pulley, and might cause a serious accident. To prevent this, the ropes, instead of being attached directly, are connected to a tension apparatus which distributes the weight and puts an equal quantity on each. The two ropes, *a a* (Fig. 315) are terminated by an ordinary capping, *b b*, through which is passed an ordinary chain, *c*. This chain is endless and passes round a polygonal drum, *d*, on the top of the cage, but the sides of the polygon are rounded to fit the links of the chain (Fig. 316). This pulley can turn on an axis, and readily permits the chain to adjust itself to any variation in the length of the ropes. Two small cross chains, *e e*, connect the main chains, *a a*, so that in case of the breakage of either of the ropes the other one holds the load; and, finally, in case the chains, *a a*, should break, the cage is supported by a flat metal rope, having one extremity attached to the capping on the winding rope, while the other is connected to the cage. Instead of employing round balance ropes beneath the cages, two flat ones are employed, the strands of each being laid in alternate directions. By doing this, it is claimed that any tendency to twist is entirely removed.

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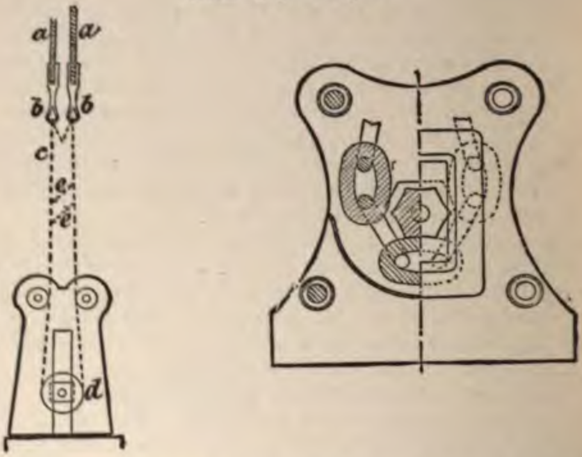
* Rev. Univ. (1879), v. 85.

† Soc. Ind. Min. (3^e Série), i. 65 and 389.

FIGS. 315 AND 316.

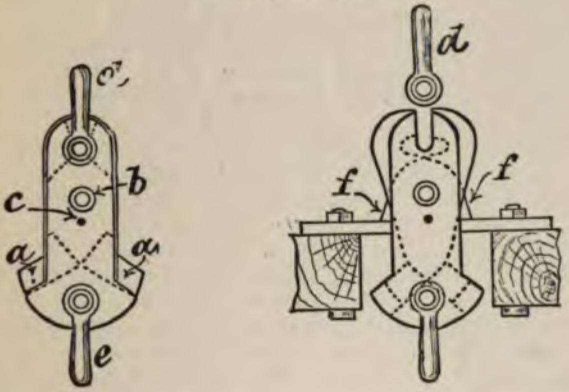


Prevention of Overwinding.—Unfortunately, overwinding sometimes takes place, and the cage and its contents are lifted too far, and dashed violently against the timber at the top of the pit frame. To prevent the rope being broken, and the cage dropped back again down the shaft, detaching hooks are employed. These may be divided into two classes; those which simply detach the rope from the cage, and those which detach the rope, and, at the same time, prevent the cage from falling. The former were first employed, but as additional means had to be provided for holding the cage when released, which involved the introduction of another complication, they have entirely given way to the latter, where one instrument serves both purposes.

There are many efficient disengaging appliances in use, all of which perform their work well, and only differ from each other in matters of detail. Perhaps the best known ones are King's, Ormerod's, and Walker's. In all of them, detachment is effected by passing the rope through a circular hole in an iron plate, or through an iron cylinder, the size of which is sufficient to allow a portion of the hook to pass through in its working state, but not to allow it to fall back again when disengagement has taken place.

King's hook consists of two outside fixed plates, enclosing between them two inner movable ones, which can oscillate about a strong pin passing through both plates and framework. The upper end of both these plates is made of uniform width, except near the bottom, where two projections (*a a*, Fig. 317) are fixed, which prevent the hook from passing entirely through the hole in the disengaging plate. The winding rope is attached to the top shackle, *d*, and the cage to the lower one, *e*. When the two movable plates are placed on the central bolt, *b*, their upper parts close in opposite directions upon the connecting pin of the winding rope shackle, and entirely overlap it, and in such position are secured by a copper pin, *c*. In case of overwinding, when the hook passes into the ring of the disengaging plate, the two projecting pieces, *a a*, are forced inwards, the copper pin sheared, and the jaws at the top forcibly separated from each other, releasing the shackle pin, *d*; at the same time the two projecting pieces are forced outwards, *f f*, and prevent the cage dropping back (Fig. 318).

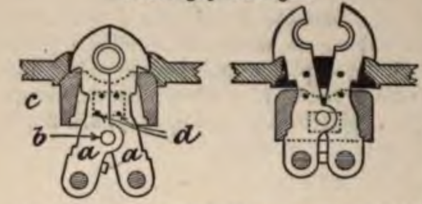
FIGS. 317 AND 318.



Ormerod's hook is very similar to the foregoing one. The only objection that can be raised against either of them is that, being constructed of plates, there is a considerable amount of side friction, and unless they are regularly taken apart and oiled, there is a probability that the plates will firmly rust together.

Walker's hook acts on an entirely different principle. In those just described, the weight is utilised to prevent displacement, while here the load is always endeavouring to cause detachment, but prevented from doing so by a hoop encircling the hook. Its construction will be understood from Fig. 319. Two levers, *a a*, are pivoted about the centre, *b*, and kept from opening under ordinary conditions by the collar, *c*, held in position by the copper rivets, *d*, which also secure an additional safeguard, consisting of a tongue passing from one jaw to the other. When the hook enters the plate, the collar is pushed downwards, and the two rivets sheared; the upper part of the jaws open, release the winding shackle, and lock the suspension jaws on the disengaging plate (Fig. 320).

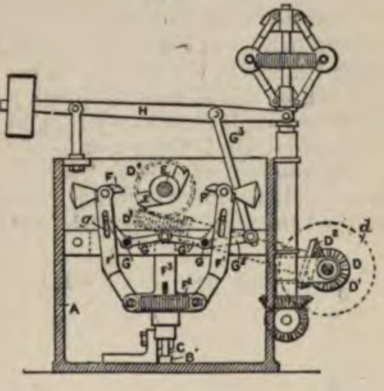
FIGS. 319 AND 320.



Safety Cages.—The apparatus just described do not safeguard the cage in the event of the rope breaking. To perform this operation, innumerable devices have been designed, none of which have, however, met with permanent success in this country, although many are working on the Continent. These safety cages usually depend on the action of a grip, which is kept away from the guides so long as the weight of the cage is borne by the rope, but immediately fracture occurs, a spring, which has been kept in compression, is released, and the grips clutch the guides and prevent falling. The objections to such appliances are numerous. At modern collieries, the velocity of the descending cage approaches that of a falling body, and there is always a danger of such appliances coming into action when not wanted. Then again, the result of suddenly stopping a cage travelling at such a speed would be that, unless the safety apparatus was exceedingly strong, in all probability it would break and release the cage, while if it was strong enough, perhaps the guide ropes would be broken. In either case, if men were travelling in the cage, the probabilities are that the shock would be so great that they would be thrown out; indeed, instances are on record where with a detaching hook the velocity of the ascending cage has been so great, when detachment has taken place, that men have continued on in obedience to Newton's first law of motion, and have been seriously injured by being dashed violently against the top of the cage, even after the latter had stopped. The best safeguard against ropes breaking is to employ none but those of the very best quality, and to give them careful treatment and regular and efficient inspection.

Automatic Contrivances.—Detaching hooks do not prevent overwinding; they only reduce the damage done, and often prevent loss of life. In addition, they do not safeguard the descending cage. Two classes of automatic contrivances are used. In one, some projecting lever is fixed above the pit's mouth, which when struck by the cage, puts on a brake; these are not any more effective than disengaging hooks, as they come into operation too late. In the other type, an instrument is so arranged that, providing the engineman shuts off steam at the proper moment, he is in exactly the same position as if no such appliance existed, as it does not come into action; but if at a determined point in the wind the speed is greater than it should be at that point, the steam is cut off from the engine, and a brake applied.

FIG. 321.



The Visor.—In this appliance, which has been in use by the Wigan Coal and Iron Co. for some time, a shaft, E (Fig. 321), carrying two beaked cams, E^1, performs one revolution to each wind, such motion being obtained by the bevel gearing and endless screw, shown at D and D^4. At each side of this cam is a tappet, F, which is engaged by one of the beaks, if the engines are going beyond the proper speed, such engagement being performed by the aid of the governor and levers, H and G^3. Usually two governors are provided, weighted for different speeds. What takes place is as follows: when the engine is travelling at high speed, the rise of the governor lifts up the lever, H, and throws the two tappets, F, into the path of the beaks, E^1, on the revolving shaft, E. If the speed decreases at the proper moment towards the end of the wind, the governor falls and throws back the tappets, F, consequently the appliance does not come into action, but if the engines are travelling above their proper speed, one of the beaked cams catches the tappet, F, and raises it; the arms, F^1, cross head, F^2, and bar, F^3, are raised also, and the pawl, C, disengaged from the catch bar, B^1. Immediately this takes place, the brake is applied and steam shut off. A somewhat similar appliance has been designed by Mr. C. H. Cobbold,* which also acts through a governor.

Grimmitt's Apparatus.†—Both the appliances just described are open to the objection that the engine receives a great shock by the sudden application of the brake. In Grimmitt's appliance, which has been very recently introduced, this difficulty has been overcome by employing a pneumatic arrangement, which buoys up the brake lever for a few seconds after such has been cast loose by the apparatus. As air escapes from a regulating tap, the air-vessel and lever sink lower and lower, gradually increasing the pressure of the curbs on the brake wheel.

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* Fed. Inst. i. 61.

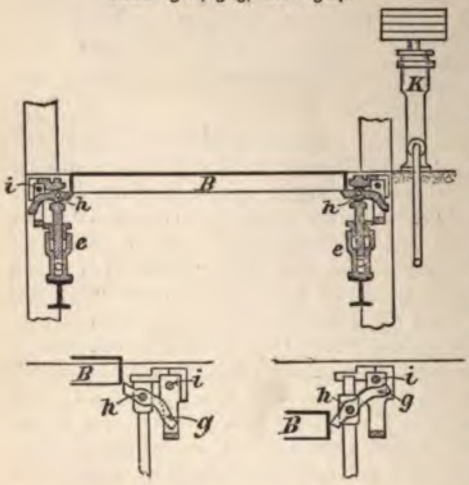
† *Ibid.*, ii. 243.

Catches at Pit Top.—At the great majority of collieries, some appliance is used to hold the cage while the changing of the tubs takes place.

Keps.—The common form consists of a series of legs, usually four, arranged in pairs on two sides of the cage. They are pivoted on a shaft, and are readily pushed aside by the cage on its upward journey, but have to be moved out of the way again to allow the cage to descend. Such form is shown at *d*, Fig. 334. In another form, a series of projecting bolts are arranged in the main timbers at the top, which are pressed outwards by springs, and can be moved back by levers. Such type is not so suitable for heavy loads as ordinary legs, as the wear is considerable, and a greater strain is thrown on the framing at the pit top.

Hydraulic Keps.—With the ordinary form of legs, if the cage is at bank, it cannot descend without being lifted off the props, as the banksman cannot withdraw these while the weight is on. If a three-deck cage is used, and each deck changed independently, seven reversals of the engines have to take place, each deck requiring two, and the final lowering of the cage another. This not only occupies time, which is so valuable in winding, but causes considerable wear and tear of the machinery and consumes steam. In addition, slack rope is payed out on to the bottom cage, and as this is usually quickly drawn up, a very injurious shock is given to the rope. Several devices, all coming from the Continent, have been designed with a view of securing the cage

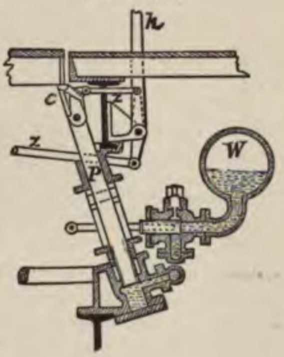
FIGS. 322, 323, AND 324.



firmly while changing is going on, but to release it again for descent into the shaft, without the preliminary lift of a foot or so, and consequent reversal of the engine.

Frantz's* appliance used at Camphausen Colliery, Saarbrücken, consists of four plunger cylinders, *e* (Fig. 322), provided with stuffing boxes and pistons, joined together by wrought-iron tubes. Each plunger is provided with a double lever, *g*, having its turning point on the piston itself. One end of this lever projects under a fixed pin, *i*, while the other serves as a support to the bottom of the cage. The rise of the piston and double lever is caused by water in the accumulator, K. The ascending cage, B, lifts the front end of the lever, *g*, upwards (Fig. 323), which by reason of its own weight falls back into the horizontal position immediately the cage has passed. When the cage rests on the legs, it is supported by the water in the piston, connection between the plunger cylinder and accumulator being cut off by a tap. When the cage has to be lowered, this tap is opened, and the weight of the tubs and contents presses down the plunger, drives back the water in the accumulator until the lever, *g*, takes the position shown in Fig. 324. As soon as the cage has passed through, the accumulator again forces the piston and lever into the higher position, and the tap above referred to is closed.

FIG. 325.



At Camphausen I Shaft, a somewhat different arrangement is in use. The four pistons, *p*, stand obliquely and have at the top an end, *c* (Fig. 325), turning round a bolt. When the hydraulic apparatus is not required, these legs, by means of the lever, *h*, and the connecting rod, *z*, can be pushed backwards and forwards just as in the ordinary way. A still greater variation consists in using an air vessel, W, instead of an accumulator. This vessel is filled with water up to the middle, the upper space containing air at a pressure of two atmospheres, which serves the same purpose as the weight of the accumulator, but by reason of its elasticity works more advantageously.

The disadvantage of such apparatus is its complicated nature, liability to get out of order, and the fact that in cold weather the water freezes. The latter has been overcome by employing glycerine in the rams and accumulators.

Stauss Props.—These are an ingenious arrangement of levers, without any complicated parts, designed to secure the same object.

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* *Lehrbuch der Bergbaukunde.* G. Köhler, 1884, p. 386.

With them only one reversal of the engine takes place, that is immediately the cage is brought to bank, the direction of movement being always afterwards a lowering one. The apparatus consists of two shafts, *a* and *b* (Figs. 326–328), fixed in bearings; the legs, *c*, upon which the cage rests, are threaded on another shaft, *d*, which can swing about, but is attached by a link to the shaft, *a*. The shaft, *d*, is connected to *b* by a toggle-joint lever, *e* and *f*. As shown in Fig. 326, it is impossible for the props, *c*, to slide in a horizontal direction, as the two levers, *e* and *f*, prevent such motion, but they allow the cage to pass through when coming to bank, for, being loose on the shaft *d*, they rotate about their axis, and take the position shown by the dotted lines, dropping back on to their seating as soon as the cage has passed. When lowering is desired, the banksman pulls over a lever, moves the link *g* in the direction shown by the arrow, and rotates the shaft *b*. This lifts up *f*, until the point *h* is a little above the straight line joining *d* and *b*. Immediately this takes place the weight of the cage does the rest, as the props, *c*, slide on an inclined plane, *i*, having a slope of about 9°. The whole apparatus takes the position shown in Fig. 327. The simplicity of the appliance is its chief recommendation, while its cost is not more than the ordinary form of legs. Its wear should be unlimited, as there is nothing to get out of order. The author has recently applied the only one in use in this country. The colliery, however, is only being opened, and no results can be given of its performances, but at Bascoup, where he first saw it in operation, it is claimed to effect a saving in time of 15 per cent. With it, 78 to 88 cages per hour have been drawn up, and the three decks changed, from a depth of 268 yards.

FIGS. 326 AND 327.

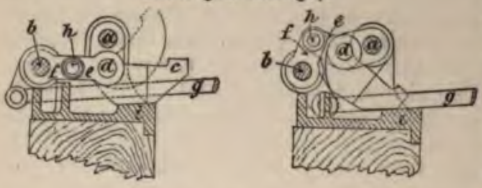
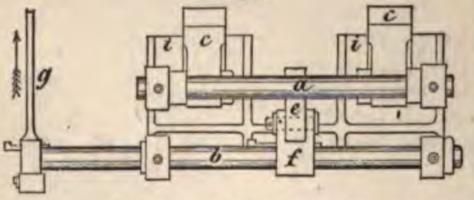


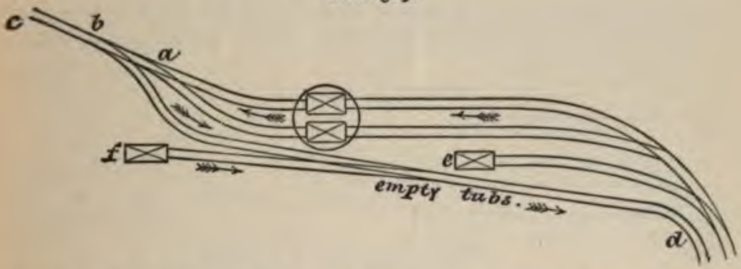
FIG. 328.



Changing Tubs.—In order to avoid moving the cage so many times, it is usual, when it has several decks, to change two of these at the same time. Supposing the cage has four platforms, the first and third will be changed at one operation, the cage will then be moved and the second and fourth decks changed. By doing this, the cage is only moved once, where otherwise it would have to be moved three times. It means more labour, because with only one landing, one set of men will do the work; with several landings, a set of men will have to be employed in each.

Hilda Colliery.—The general method of caging two decks at once is well illustrated at Hilda Colliery, South Shields, where the details have been carefully thought out. The inset is divided into two stages, and all the tubs from the workings arrive at the top level and run down a gradient of $\frac{1}{2}$ in. to the yard, either to the shaft to supply the top platform, or to a drop cage, by means of which they are lowered to the bottom level to supply the bottom deck. A plan of the arrangement of the rails is given in Fig. 329. The empty tubs from the top deck gravitate down an inclination of $3\frac{1}{8}$in. to the yard to the point, *a*, and are carried by the momentum they have attained for a short distance along *a b*, and up a slight gradient, *b c*, sufficiently far to clear the points, *b*. Their direction of motion is reversed, and they then run along the line marked "empty tubs," indicated by the arrow, and deliver themselves to the point, *d*, where they are made up into sets and hauled away to the workings. The full tubs for the lower decks, after being dropped by the cage, *e*, gravitate to the shaft, and the empty ones towards the cage, *f*, which is connected by a rope to the drop cage, *e*. As the weight of the latter and the full tubs is heavier than that of cage *f* and its empty tubs, when *e* is lowered it lifts up *f* and the empty tubs to the top level, where they are automatically released from the cage, and gravitate away to join those at *d*, which have already come from the top deck.

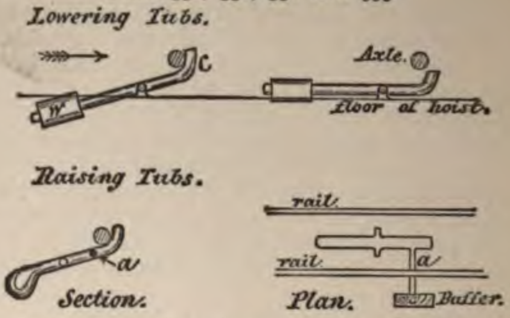
FIG. 329.



The following automatic catches are used for keeping the tubs on the cages during their ascent or descent: (*a*) During lowering, the tubs run in from the direction shown by the arrow (Fig. 330), the axles being caught by the catch, *c*, maintained in position by the weight, *w*. On reaching the bottom the weight strikes the floor and lowers the catch, allowing the tubs to run off (Fig. 331). (*b*) When raising tubs; the position at the bottom is shown by

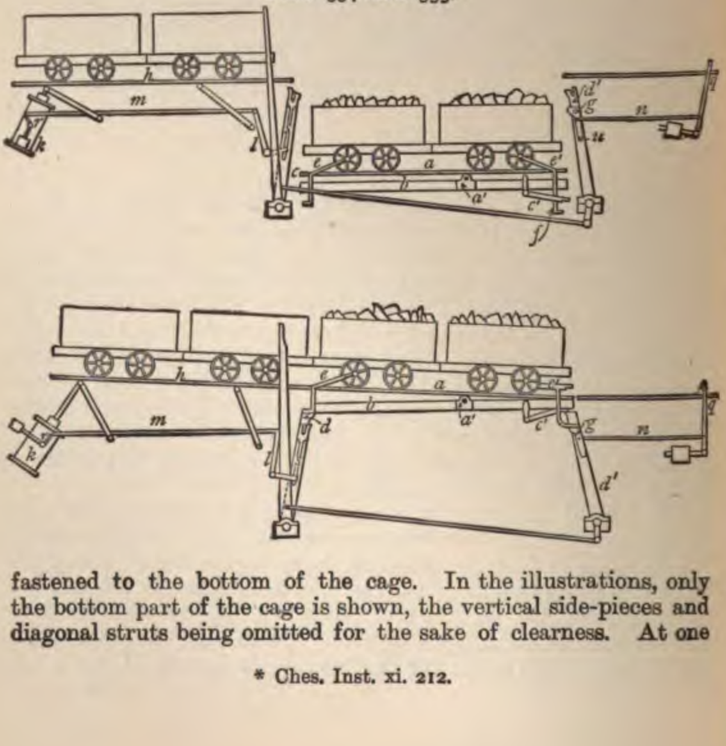
Fig. 332; on reaching the top the cranked lever *a* strikes a buffer at the side which liberates the tub (Fig. 333).

FIGS. 330, 331, 332 AND 333.



Clifton Colliery.—Mr. Henry Fisher * has designed an arrangement in which the rails (*a*, Fig. 334), are pivoted about a point, *a'*, fastened to the bottom of the cage. In the illustrations, only the bottom part of the cage is shown, the vertical side-pieces and diagonal struts being omitted for the sake of clearness. At one

FIGS. 334 AND 335.



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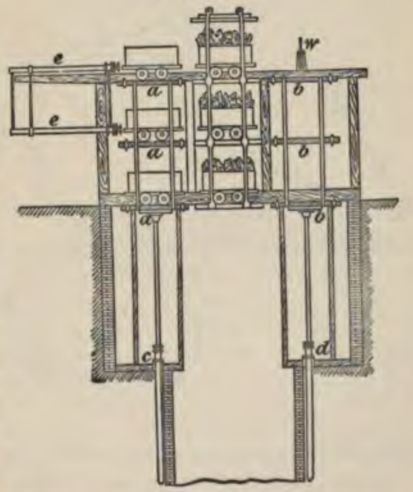
* Ches. Inst. xi. 212.

end of the rails are two feet, *c*, and at the other, two levers, c', projecting below the bottom of the cage when it is suspended. When the cage is lowered, the feet *c* rest on the props, *d*, and raise the rails at that end of the cage, while at the same time the lever, c', rests on the props, d', and lowers the rails at the other end, the result being that the tubs gravitate away. Before the rails are inclined, the tubs are held on the rails by the stops, $e\ e'$, which press against the axles, but simultaneously with the rails, *a*, being inclined, a foot, *f*, attached to the stop, e', rests on the prop, *g*, and raises it to the position shown in Fig. 335, and allows the loaded trams to run away. The prop *g* is pivoted about a shaft, *u*, and is connected by a rod, *n*, to a lever, *q*. When the axle of the first loaded tram presses against this lever *q*, the prop *g* is withdrawn from under the foot *f*, and the stop e' takes the position drawn in Fig. 334, in time to prevent the empty tubs running through the cage.

In addition to the tub-releasing gear, the empty trams are run on the cage by the aid of a movable platform, *h*, connected with an oscillating cylinder, *k*, to which air or steam is admitted by an ordinary three-way cock, *r*. Simultaneously with the inclining of the rails on the cage, the foot *c* presses down the tappet rod, *s*, and gives motion through the crank lever, *l*, to the connecting rod, *m*, which opens the tap, *r*, and admits steam to the cylinder, when the platform, *h*, is raised to the same inclination as the rails on the cage (Fig. 335). As soon as the cage is lifted from the props, steam is discharged from the cylinder, and the platform, *h*, falls to the horizontal position. The oscillating platform seems to be an unnecessary complication, as the rails might easily be arranged on a permanent incline.

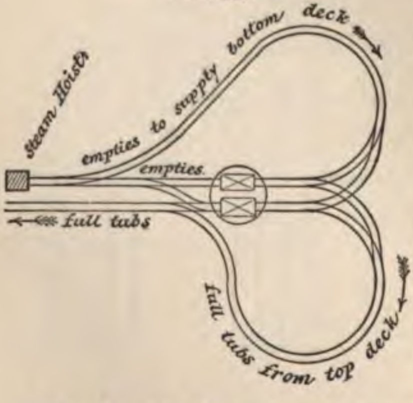
FIG. 336.



Fowler's Apparatus.—At several of the collieries in the Nottingham district, Fowler's apparatus is used for simultaneously changing all the decks of the cage. Fig. 336 shows the apparatus in the position when the cage has just arrived at bank with its load of full tubs; the platforms *a a a* contain the empty tubs, while *b b b* are ready to receive the full ones. The tubs on the lower platform are pushed off by manual labour; simultaneously with this, the empty tubs on the two upper decks are thrust forward by the hydraulic rams, *c c*, and displace the loaded ones on the cage. The catches for retaining the empty tubs are then put into position by the movement of one rod (not shown) and the cage is ready to proceed on its downward journey, the time occupied in changing being exactly the same as if only one deck was in use. The two platforms, *a* and *b*, are then allowed by the hoists, *c* and *d*, to sink; *a* is ready to receive empties, its decks being successively brought by the hoist to the bank level, and *b*, having been allowed by similar means to bring its middle deck to the bank level, can be further lowered for the removal of its uppermost loaded tub. As soon as this is done, the counterbalance weights W, bring it back into position ready to receive the full tubs again. Time is saved in changing the tubs on the cage, because the operations of taking off the full tubs and putting the empty ones on the hoist is performed while the wind is taking place. At Denaby Main Colliery, Yorkshire, where the author saw the appliance in operation, six tubs were changed on three decks in ten seconds. Everything worked well and successfully, but seemed to require a lot of labour.

Harris Navigation Colliery.—At the downcast pit, two decks are changed at once. The full tubs run off the top deck, in the opposite direction to those going off the bottom deck, and proceed round a circular platform, having a gradient of about 1 in 40, to the other side of the pit, where they join the loaded tubs from the bottom deck, the whole lot then going to the screens. The empty tubs to change *both* decks are raised by a steam hoist to a platform about 6 ft. 6 in. high; part of them run straight to the shaft (to change the top deck), while the other part run round a second circular platform with a descending gradient, and reach the opposite side of the shaft, where they are placed on the lower deck of the cage (Fig. 337).

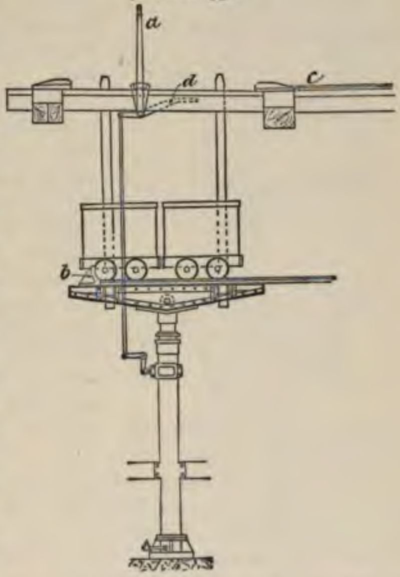
FIG. 337.



The steam hoist discharges its tubs automatically, as a stop is placed in the guides which tilts up the bottom. The cages are also provided with a loose bottom, pivoted about a pin. By an arrangement of projecting pieces and tub stops, similar to those in use at Clifton, the tubs automatically discharge themselves as soon as the cage is lowered on to the keps.

Bell End Colliery.—At Bell End Pit, where the shaft only contains one cage, the author is employing a combination of several arrangements. The cage is double-decked, and each is changed independently. The rails are set at a permanent inclination, and the tubs are kept on by a hinged arm, but at the landing-place are released by an automatic arrangement described a little later on. At the bottom, the lower deck is received on a set of Stauss props, the tub is released and gravitates away to a platform. The cage is then lowered without reversing the engine, and the top deck tub released, which then runs to the same platform. The full tubs are now on the cage, which starts away to bank.

FIG. 338.



The platform referred to is attached to a hydraulic ram and pivoted about a point slightly away from its centre (Fig. 338). When the tubs are on, it therefore takes a certain inclination limited by a stop. The curved guard, *b*, prevents the tubs running through, and the inclined surface will not allow them to pass out during the lift. The hanger-on pulls the lever, *a*, the platform and its contents rise a distance of about 6 feet. On arriving at the top the platform automatically stops through catching the lever, *d*, and cutting off the pressure, and is tilted in the opposite direction, when the tubs run away on the top landing, *c*, and gravitate to the point where they are attached to the haulage ropes; the platform then descends, ready to receive another consignment of empty tubs.

The releasing gear employed is that designed by Mr. W. R. Wills.* The inclination of the rails is such that the tubs will only run forwards, and these are held on and released from the cage by the mechanism shown in Figs. 339, 340 and 341. The L arms, *a a*, revolve in suitable bearings fixed to the side of the cage, and the angle pieces rest against the front end of the tub, but are prevented from rising too high by a stop (not shown in illustrations), while they are kept in their proper place by a spiral spring, *b*, attached to levers, *c c*, projecting outwards. On the cage being drawn out of the shaft these levers strike against and lift two catches, *d* (Fig. 339), which fall back into place again, and on the return of the cage push the levers, *c*, into the position shown by the dotted line in Fig. 341, and release the tub. By the time, however, that the cage rests on the legs the levers, *c*, have completely passed the catches, *d*, and the arms, *a*, would be closed by the springs, *b*, but by such time the L parts of the arms are locked beneath the bottom of the tub, and remain there, until it has passed out, when they immediately close and prevent the further passage of the second tub.

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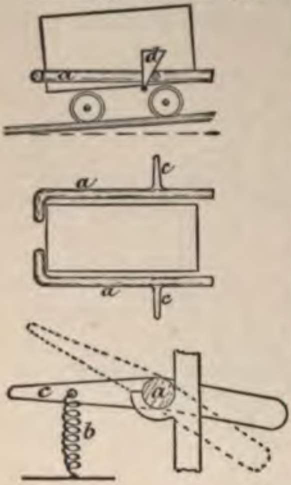
* So. Staff. Inst. iv. 31.

FIGS. 339, 340 AND 341.



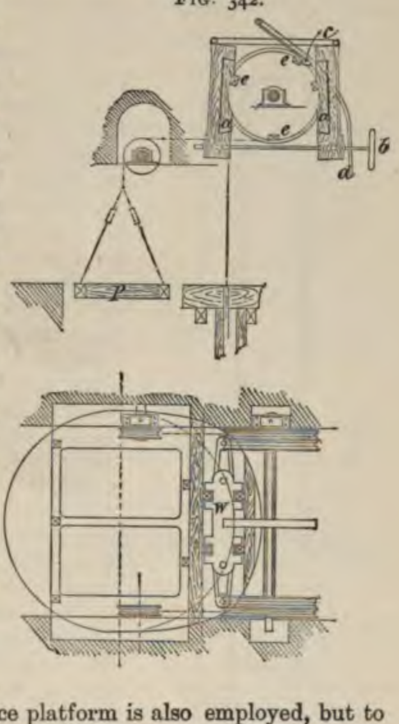
At the surface, the cage is lifted until its bottom deck rests on the Stauss props, and the motion afterwards is always a lowering one. The tubs are automatically released by a similar apparatus to the one at the bottom.

Bascoup Colliery.—At No. 5 Pit the changing operations are performed with extreme rapidity; at the bottom with the aid of a balance platform, and at the top with Stauss keps; and, by the peculiar arrangement existing there, both are carried on independently of each other.

When the cage reaches the bottom it is received upon a platform, *p* (Fig. 342), counter-balanced with a weight, *w*, equal to that of the empty tubs and the cage. The two empty tubs on the bottom deck are then replaced by full ones, and the extra weight of the load they contain causes the cage to descend with the platform, until the second deck is level with the inset. The tubs on this deck are then changed, and the platform and cage descend again, until the top deck is level with the inset, when the empty tubs are replaced by full ones. The descent of the platform is governed by a brake, *a*, regulated by a hand-wheel, *b*. A catch, *c*, is also provided, which locks the platform at the proper levels, by engaging with the stops, *e*. This catch can be lifted off by an arm, *d*. It will allow the platform to *ascend*, but not to descend until released. Immediately the cage containing the full tubs is lifted by the winding engine, the counter-balance brings back the platform to the level of the inset, ready to receive the other cage.

The changing at the surface is carried out as follows. The bridle-chains are made very long, and before the top cage comes to bank, the bottom cage reaches the balance platform just described. At this point the engine is steadied, and the top cage is lifted until its lower deck rests on the Stauss props. An amount of slack rope is, therefore, payed out on the cage at the bottom by such operation, but through the bridle-chains being long the rope itself is kept straight, and does not "kink"; indeed, not so much is let out as would be expected, for before the top cage is actually raised to bank, the empty tubs on the bottom deck of the cage below ground will be replaced by full ones, and the platform lowered, thus taking up a length equal to the height of one deck. At the surface the bottom deck is also changed first, the cage lowered by moving the Stauss props, the full tubs on the second deck replaced by empty ones, the cage again lowered and the top deck changed. The engineman has only to attend to the operations at the surface, the tubs at the bottom being changed with the balance platform, and by the time the top deck is changed at the surface, all the slack chain and rope has been taken up, and the engine starts away upon receiving the signal from the bottom.

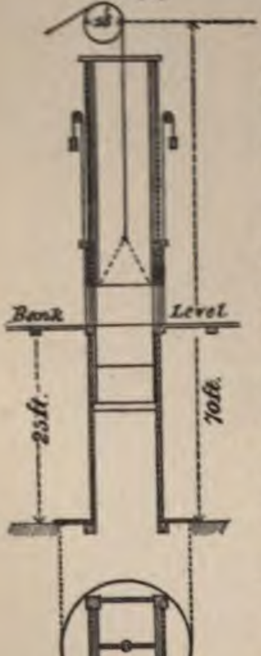
FIG. 342.



At Anzin Colliery a balance platform is also employed, but to remove any chance of the rope kinking when the slack rope is payed on to the cage, a short length of aloe rope is inserted between the bridle-chains and the capping of the steel rope. As this is quite soft and flexible, no harm can result.

Fencing the Pit Top.—To allow the empty tubs to run on, and the full ones off the cage, a movable fencing has to be employed at the pit top. This usually consists of sliding gates opposite the ends of the cage, a permanent fence being erected on the other two sides. Projecting pieces on the cage top catch these gates and lift them upwards when the cage arrives at bank, but as soon as the descent commences the gates fall to the ground and secure the top of the shaft. As the cage travels at considerable speed when it strikes the fence, it is advisable that the latter should be made as light as possible. The preferable plan appears to be to employ three strips of iron connected together by chains; the top one is longer than either of the other two, and rests on two props in its normal position. On the arrival of the cage at bank, the bottom piece of iron is first lifted, then the second, and finally the third.

FIG. 343.



The problem is rather more complicated if winding goes on at an up-cast shaft where fan ventilation is employed, because, unless some special means are adopted when changing is taking place, the pit top is open to the atmosphere.

Pemberton Colliery.—At the up-cast pit, the entire distance from the ground level to near the top of the frame is cased in, as shown in Fig. 343, by two rectangular sheaves of wood, each forming a compartment in which one cage travels. As little play as possible is given between the sides of the cage and the framing, each cage practically forming a piston. At the banking level, small rectangular openings are made, of just sufficient size to allow the passage of the tubs through them; these openings are closed on the inside by a vertical trap-door sliding in two grooves, which is opened by the cage as it ascends, and on the outside by a safety trap-door, balanced by a weight which is lifted by the on-setter. By this method, the loss of air is reduced to a minimum. The bottom deck of the cage is made solid, and to prevent any loss of air when standing at bank, it is provided with a second or false bottom, about 18 in. below the one on which the tubs rest. By this device the top of the pit never becomes open to the atmosphere, even should the engineman raise the cages a short distance above the proper level. To provide a perfect joint, and reduce shock, the inside doors have a gutta-percha band running along the lower side.

Homer Hill Colliery.—Another method of covering commonly employed is well illustrated by that in use at this colliery. The shaft is closed by a pyramidal covering, at the upper end of which is a small movable shutter. The pressure of air on the outside of this pyramid, owing to the vacuum beneath, is considerable, and it is, therefore, counter-balanced by weights, *w* (Fig. 344). When the cage is nearly at bank, the capping on the winding-rope first lifts the small shutter, *a*, and it does so easily as its area is small. This to a certain extent takes off the pressure on the main casing, and as the weight of the latter is also counter-balanced, the cage lifts the covering vertically upwards without any injurious shock. As an additional safeguard, springs, *b b*, are placed at the four corners.

FIG. 344.

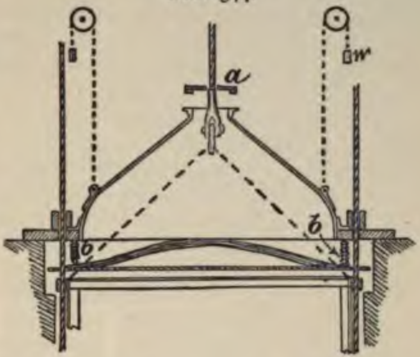
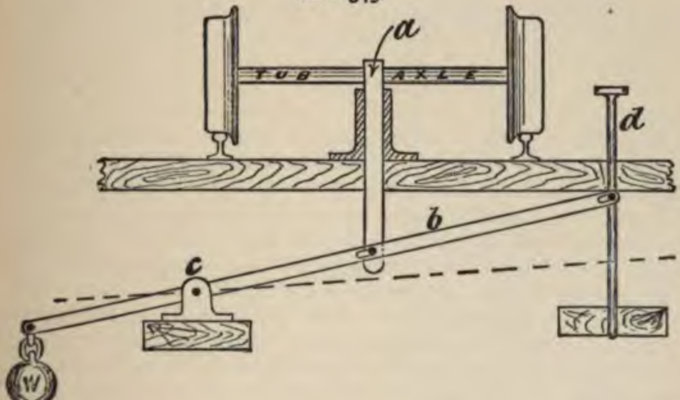


FIG. 345.



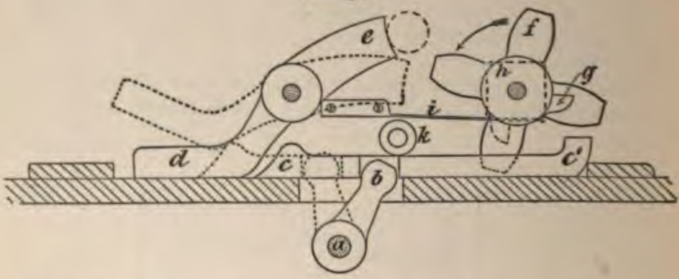
Tub Controllers.—To prevent the tubs running into the shafts, ordinary blocks (Fig. 216) are generally employed, but possess many disadvantages. They have to be opened by hand, and when once open will allow any number of tubs to pass by. Automatic contrivances are much to be preferred.

At Lye Cross Pit, the empty tubs are controlled by a projecting stud, *a* (Fig. 345), which stands up between the rails and catches the axle of the tubs. This stud is attached to a lever, *b*, pivoted about a centre, *c*. One end of the lever is weighted, *w*, while the other is attached to a foot treadle, *d*. The weight always keeps the lever in such a position that the stud, *a*, blocks the way, unless the banksman depresses the treadle. This apparatus has two objections: (*a*) as the stud engages the *middle* of the axle, this may get bent; and (*b*), the banksman has to keep his foot on the treadle until the tub has passed by.

For empty tubs the former is not of much importance, as little strain is thrown on the axle, but for loaded tubs the objection is fatal. The latter is scarcely any inconvenience, as the apparatus is very compact, the treadle can be placed anywhere, and the banksman, having the use of both hands, is left quite free.

To the apparatus used at Bell End Pit for regulating the passage of the full tubs no objection can be raised. It is designed by Mr. B. Woodworth, and can either be arranged to automatically control the delivery of tubs in and out of cages, or for intermittent delivery from inclined planes or platforms without the need of attendants for scotching and releasing the tubs. The apparatus can be opened from any distance by the person requiring the tubs, and all the other movements are self-controlling.

FIG. 346.



To open the controller, the shaft, *a* (Fig. 346), is twisted and moves the tongue, *b*, causing the sliding bolt, *c*, to project under the lever, *d*, and lowering the stop end at *e*, until the axles run clear, when delivery by gravitation commences. The succeeding axles turn the star wheel *f*, in the direction shown by the arrow, as they pass by, until the cam point, *g*, comes into contact with the heel of the sliding bolt, *c*, at *c'*, and withdraws the same, causing the lever, *d*, to fall into its proper position and stop the delivery of tubs until it is reopened in the usual way.

To check any tendency there may be for the star wheel, *f*, to travel beyond its right position when driven by the axles of the tubs, it is provided with a square boss, *h*, upon which a spring, *i*, presses. A small roller, *k*, is fixed over the sliding bolt, *c*, to prevent any tilting up of the latter when heavy loads are pressing against the buffer stops.

Either when used on cage decks, or on inclined platforms, two controller boxes are fixed between the rails, so that the buffer stops come into contact with the tub axles as close to the bearings of the wheels as possible; by doing so, there is little risk of bending the axles by the shock of stoppage of the loaded tubs, and, as an additional preventive, elastic spring buffers are also used to equalise the bearings of the axles against the stops. In Fig. 346, the box mechanism shows an arrangement to pass two tubs each time. To pass one only each time, two cam points, *g*, are used to one star-wheel boss, while for passing three tubs, a star-wheel with six points would be used with only one cam point.

Signalling.—Nothing conduces to rapid winding more than efficient signals. Two systems are employed. The ordinary method consists of a wire carried down the side of the shaft, one end being attached to a lever and the other to the mechanism working a bell. For small depths this system works very well, but where the line is a long one, the power required to ring the bell is considerable, and although balance arrangements are used to take off the weight, the banksman has still to exert a large amount of force, which necessarily takes time.

Instead of these mechanical signals, it has now become common to use electrical ones. Undoubtedly, when such were first applied, they were by no means suitable for the rough work of a colliery. The great mistake made consisted in making them far too weak, and not introducing sufficient safeguards; in addition, the men at collieries were quite unused to such appliances, and if anything went wrong, an electrician had to be sent for. At the present time none of these objections hold good. It has long been recognised that signals suitable for dwelling-houses are of no use whatever at collieries, and a special stronger type has been designed. The working and keeping in order of such appliances have ceased to be a wonder, and many collieries at the present time simply purchase their stores, and fit up and keep the signals in order themselves.

What are known as single-stroke bells are generally employed, that is to say, the bell only makes one stroke each time a signal is given. The elements of successful working principally lie in having large-sized battery cells, which are almost universally of the Leclanché type, and proper wire in the shaft. One of these wires should undoubtedly be insulated. Sometimes both wires are suspended from a point on the head-gear and hang free in the shaft; then neither are covered. This arrangement possesses some advantages in the fact that it is cheap and requires little labour and in addition the wires are not damaged by pieces of coal, &c., falling down the shaft, as these simply glance off the wire and do no harm. Sooner or later, however, leakage of the current takes place. The better plan, although the dearer one to commence with, is to employ a properly insulated wire and carry it in grooved boarding down the side of the shaft. No staples or iron should be employed to keep the wire in the groove, which should preferably be made slightly smaller than the diameter of the covered wire, and then the latter lightly tapped into place, the whole being finally covered with a light wooden lid. The insulation prevents leakage, and the wood casing any damage to the insulation.

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SO. STAFF. INST. : *An Improved Arrangement for Steam Brakes*, T. Pasfield, ii. 112; *Self-acting Caging and Banking Apparatus*, W. R. Wills, iv. 31; *Winding-Engines*, H. W. Hughes, xii. 21.

SOC. IND. MIN. : *Note sur le chevalment en fer du puits Robert*, M. Robert (2^{e} Série), ii. 295; *Tube atmospheric du puits Hottingeur*, Z. Blanchet (2^{e} Série), iv. 557 and vii. 273; *Guidage des puits de mine*, H. Fayol, de Beauzat, et Chanselle (2^{e} Série), vi. 697; *Comparison des divers modes des Guidage, Rapport d'un Commission*, MM. Mirc, Pinel, Griot, Desjoyeaux, et Barietta (2^{e} Série), vi. 750; *Machines d'extraction et machines motrices à l'Exposition de Paris* (1878). M. Rossigneux, (2^{e} Série), viii. 789; *Note sur la descenderie de remblais du puits de Lyon*, M. Griot (3^{e} Série), iii. 365.

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SO. WALES INST. : *Safety Detaching Hooks, &c.*, S. Humble, xii. 45, Appendix by Hort. Huxham, xii. 191; *Wire Ropes*, T. H. Deakin, xvi. 305.

CHES. INST. : *Coal Winding in Deep Shafts*, A. H. Stokes, vi. 248; *Self Acting Arrangement for Unloading and Loading Colliery Cages*, T. G. Lees, xi. 209; *The Koepe Patent System of Winding at Bestwood Collieries*, Robert Wilson, xi. 267; *Counter-balancing the Weight of Winding Ropes*, C. Meinicke, xiii. 333; *The Application of Meinicke's System of Balance Ropes to Winding with Flat Ropes*, J. C. Jefferson, xiv. 230.

AMER. INST. M. E.: *The Equalization of Load on Winding-Engines by the Employment of Spiral Drums*, E. M. Rogers, xvii. 305; *Pneumatic Hoisting*, H. A. Wheeler, xix. 107.

N. STAFF. INST.: *Some Arrangements for preventing Accidents at Level Landings in Cage Dips and Shafts*, A. R. Sawyer, viii. 204; *On Economy of Steam practically obtainable in Winding Engines*, B. Woodworth, ix. 158 and 219; *The Holding Power of Glands on Wire Conductors*, A. R. Sawyer, ix. 270.

REV. UNIV.: *Note sur l'installation d'un guidonnage entièrement métallique* (*Système Briart*) L. Donekier (2e Série) iv. 211; *Système d'extraction par câbles sans fin*, L. Trasenster (2e Série) v. 85; *Note sur diverses dispositions de puits d'extraction affectés à l'aérage par appareils mécaniques*, H. Glépin (2e Série) vi. 107; *Note sur guidonnages métalliques établis aux fosses d' Havre*, Ch. Demanet (2e Série) vii. 549; *Note sur un nouveau système de taquets de retenue pour cages d'extraction*, A. Stauss (2e Série) xviii. 101.

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CHAPTER X.

PUMPING.

THE amount of water met with in mines is dependent on their depth and on the nature of the overlying strata. Shallow mines are always more troubled with water than deeper ones. The subsidence caused by extracting the material cracks and fissures the ground above, and affords means for the ingress of water. Even when the depth is great, if the strata overlying the coal seams contain large quantities of water, as is often the case, the workings naturally release the water, and it flows into the mine. In some cases, a series of impervious beds are found to exist between the water-bearing strata and the coal measures beneath, and the water met with during sinking may be tubbed back.

Pumps.—Numerous types of pumps are used for unwatering mines, but they may be broadly divided into two classes—bucket and plunger. If the engines are placed at the surface, with the former type the water is lifted during the forward stroke, while with the latter it is forced at the backward stroke.

Bucket Pumps.—Suction pumps in mines are similar to those used in ordinary wells, only better designed and on a larger scale. They consist of a pipe, called the working barrel, *a* (Fig. 347), into which a well-fitting piston, *p*, having a valve or valves opening upwards, is worked up and down by being attached to the pump-rods. The lower end of this working barrel is connected to a suction pipe, containing a valve, *c*, called a "clack." The lower end of the suction pipe is called the "snore piece," or "wind bore," and is provided with a number of holes at or near the bottom, through which water enters the pipe, and which prevent, to a certain extent, any large piece of solid material entering the working barrel. The combined area of these holes should be larger than the area of the suction pipe.

When the piston, or bucket, makes its up-stroke, a vacuum is created in the working barrel, and the pressure of air forces water through the suction pipe and clack into the working barrel. On the return stroke the clack closes, and the bucket valve opens, allowing the water to pass to the upper side of the bucket, to be raised to the surface on the return stroke of the engine.

Plunger Pumps.—In this system the water, instead of being lifted, is forced up by the action of a plunger. The arrangement of this, and the necessary valves, is shown in Fig. 348, where the piston, *a*, is just commencing its upward stroke, and is sucking water through the valve, *b*. On the return, the valve *c* will open and *b* close, and as the plunger passes downwards, water is forced through *c* to the surface.

FIG. 347.

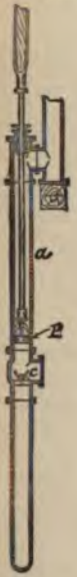


FIG. 348.

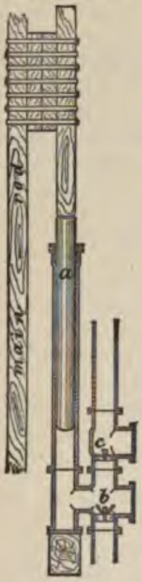
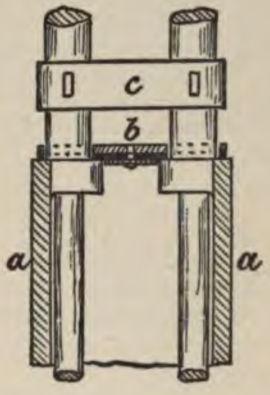


FIG. 349.



Hollow Plungers.—With bucket pumps, lighter rods can be employed than with plungers, but wear and tear is large, and the maintenance charge is heavier. Plunger pumps have one disadvantage; unless the column of water is solid at the commencement of the return stroke the ram falls suddenly, and the pipes receive a severe shock. To remove the difficulty; and to combine the advantages of both systems, hollow rams are often used; they consist of a hollow plunger, *a* (Fig. 349), having at the top a valve, *b*, which is closed during the up-stroke, and opened on the return, being prevented going too far by the stop, *c*. Such a plunger may either work through an internal stuffing-box in the rising main, or, preferably, the stuffing box is placed outside, where it may easily be tightened up without stopping the work.

Stocks or Trees.—The pipes through which the water is delivered to the surface are called "stocks," or "trees," and, in combination, form the rising main. They consist, as a rule, of cast-iron pipes, generally 9 ft. long, shorter lengths of 3 ft. and 6 ft. being used for making-up pieces. They should be as long as possible, without making them difficult to handle, as by doing so the number of joints is reduced, there being less liability for air to enter. They should always be cast standing; if not, the probabilities are that the metal will be thicker on one side than the other.

The thickness depends on the size and the pressure to be withstood. A cubic foot of water weighs 62½ lbs., and as it stands on a base of 144 sq. in., the pressure per sq. in. due to each foot in depth is .434 lbs. The common rule, and one erring on the right side, is to allow a pressure of ½ lb. for each foot in depth, or to find the total pressure in lbs. per sq. inch due to a column of water, its vertical height in feet may be divided by 2. Indeed, some allowance is absolutely necessary in determining strengths, because it is well known that the pressure experienced in pumping sets is variable during different parts of the stroke, and exceeds that due simply to the weight of the water.* The necessary thickness of the pipes is determined by the formula:

$$t = \frac{d\,p}{2 \times 2800}$$

where d = internal diam. in inches, t = thickness in inches and p = the pressure in lbs. per sq. inch.

The weight of any length of pipes is found by the formula:

$$w = c\,(D - d),$$

where w = weight per lineal foot, D = the outside diam. in inches, d = inside diam. in inches, and c is a constant = 2.45 for cast iron, and 2.64 for wrought iron.

Of late years, wrought-iron and steel pipes have been substituted for cast-iron ones. For the same strength their weight is considerably less, and they can be made in longer lengths, and yet be much easier handled; 15 to 20 ft. lengths are by no means uncommon. They have additional advantages in being cheaper, and not so liable to fracture.

Joints.—The trees are joined together in various different ways. For moderate lifts, the common practice is to face and turn in two concentric **V** grooves in each flange. A sheet of lead is placed between the two flanges, and when the bolts are screwed together, this lead is forced into the **V** grooves. The better plan for heavy pressures is to employ what is known as the male and female joint. One flange is provided with a projection and the other with a corresponding recess. An india-rubber or lead ring is placed in this groove, and the flanges screwed firmly together.

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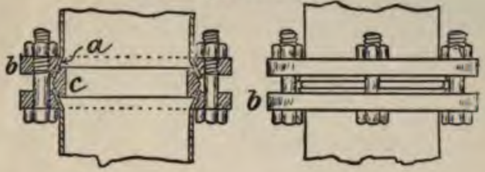
* Consult. N.E.I. xxi. 949; and Brit. Soc. Min. Stud. iii. 107, and viii. 138

For wrought-iron pipes, one of the best known joints is Williams's patent. Each pipe terminates in a short cone, *a* (Figs. 350 and 351), and is provided with a loose flange, *b*. The joint is made by introducing a double cone-shaped annulus, *c*, and screwing the flanges tightly together. An india-rubber ring is fitted upon each ferrule. The advantages are, the small amount of time taken to make a joint, and the pipes can be connected at small angles, whereby, in many cases, the trouble and expense of bends is avoided. They possess an advantage over screwed wrought-iron pipes, as they are not weakened by having threads cut on them, and when galvanised, no part is subjected to corrosion, as is the case when galvanised pipes are screwed.

FIGS. 350 AND 351.



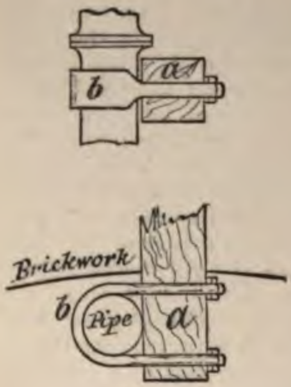
Supporting Pipes in Shaft.—The ordinary plan is to provide a main bunton of timber running across part of the shaft, upon which two smaller pieces are fixed at right angles, one on each side of the pipe under a flange. These short pieces are hollowed out to fit the pipe perfectly. It is difficult to see how such support can be improved, and it is invariably employed where there is plenty of room. It, however, requires a considerable amount of space, because the main cross-piece has to be fixed on the outside of the pipe, and as it has to bear all the weight, is necessarily large.

In a shaft where room was valuable, the author applied the method shown in Figs. 352 and 353. A bearer, *a*, was fixed at right angles to the brickwork of the shaft. Wrought-iron pipes were employed, as the flanges on them took up considerably less space than cast-iron ones would have done. One of these timber pieces was fixed immediately below each joint of the pipe. A wrought iron gland, *b*, with two screwed pin-ends passed round the pipe and through the timber piece, and was firmly bound against the tube by nuts screwed as tight as possible. A main bearer similar to that described in the preceding paragraph was fixed at the bottom of the shaft, this supporting, in a great measure, the weight of the pipes.

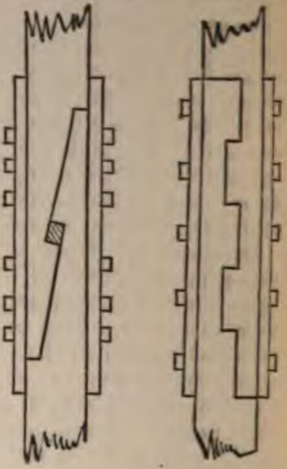
Spear Rods.—The buckets, or plungers, are connected to the engine through the medium of what are called "spear rods." In the great majority of cases these consist of wood, although iron and steel are sometimes employed. Since those above have to support their own weight and the weight of all below, the upper rods must be made proportionately large. With plunger-pumps, the rods must be heavy enough to force up the column of water before them. Wooden rods are preferably made of pitch pine, except at the surface, where they are exposed to changes of temperature. Pine is more readily obtained in long straight lengths free from knots.

If rods of sufficient sectional area cannot be obtained, they are made up of two pieces, the joints of the one coming into the centre of the other set. Single rods are sometimes jointed by cutting the ends slanting with a hole in the middle, the connection being made by an iron plate on both sides and bolts passed through. An oak wedge is finally driven into the hole in the centre to make the joint quite firm (Fig. 354), but this has the disadvantage that the wood is likely to split. The bolts are not passed through the core of the wood, but alternately on either side. A common joint is to cut off the ends of the rods square and to bolt connecting plates on all four sides.

FIGS. 352 AND 353.



FIGS. 354 AND 355.

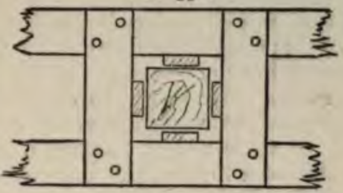


Compound rods are often put together by two pieces side by side, which may be cut so as to fit into one another (Fig. 355), or they may be simply in contact with bolts at intervals. Often the rods are connected by side irons, with the bolts outside the timbers.

Iron rods are built up of various sections fixed together with bolts or rivets, usually the latter. A general form is composed of two channel pieces, back to back, and two flat strips, one on each side, but every section of compound girder is employed.

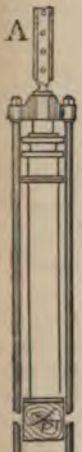
Guiding the Rods.—This is usually very simple. Two beams are placed across the shaft with cross-pieces (Fig. 356). Rubbing boards are fixed to the side of the actual rod to take up wear. Catches are also fixed, the object of which is to prevent the rods falling down the shaft should a breakage occur, and to stop the engine exceeding its stroke.

FIG. 356.

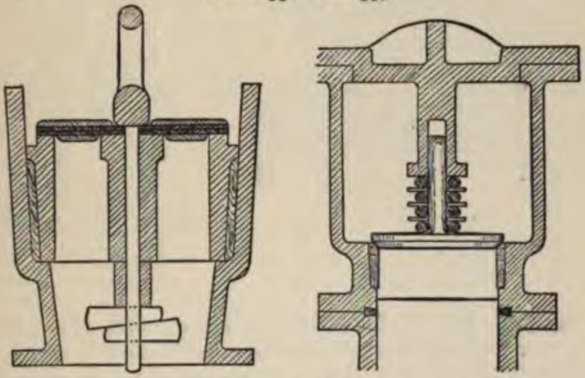


Counterbalancing.—In deep shafts, the weight of the rods becomes very great, and is more than that required by the plungers; in addition, a more powerful engine is needed to lift them. To remove this disadvantage, balance-bobs are placed at one or more points at the surface or in the shaft wherever possible.

FIG. 357.



FIGS. 358 AND 359.



Connections to Rods.—Owing to the ease with which bucket lifts can be lengthened, it is common to find one of these at the bottom and plungers higher up the shaft. This necessitates attaching the plungers to the main spear rods by some form of connection. In general, water from great depths is not forced or lifted to the surface in one operation, but in a number of stages, each of which is called a lift. It is, therefore, common to find the main pumping rod going direct to the bottom of the shaft, with plungers attached to it at intervals. These connections are often made by the method illustrated in Fig. 348, but the better plan is to fork the main rod (A B, Fig. 357), instead of placing the plungers at the side. The plunger is then fixed in the line of the rods, the latter being continued on either side, joining again afterwards.

Valves.—The simplest kind of valve is that in which a flap works on a hinge. This is the type used on the buckets of suction pumps, but it consists of two flaps instead of one (Fig. 358); clack-valves are constructed in a similar manner, but instead of fixing the hinges of the flaps, they work within guides, and the whole is free to move upwards a few inches, thus giving a greater area of water passage at the commencement of the stroke.

A valve largely employed for pumps of moderate capacity for lifts of 3 to 500 ft. is the single beat one (Fig. 359). The spindle is fitted with alternate discs of india-rubber and sheet-iron, the lift of the valve being determined by the amount of compression of the india-rubber discs.

For lifts up to 300 ft., india-rubber disc valves give good results.

FIG. 360.

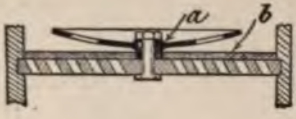
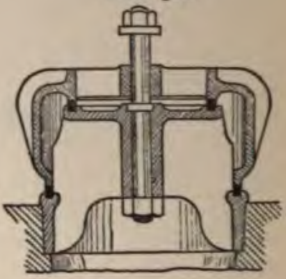


FIG. 361.



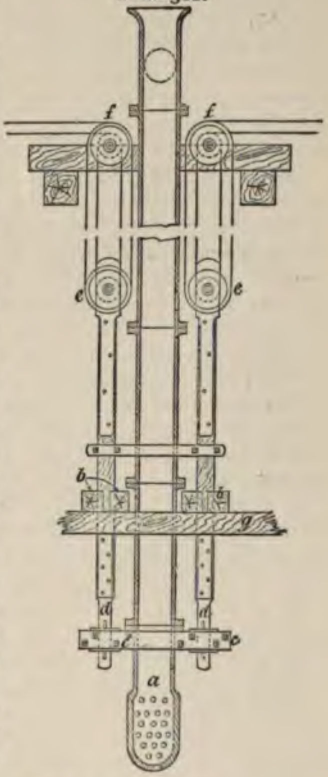
An india-rubber disc is fixed over the centre of a grid, and on the water rushing through the holes is lifted at the edges, and immediately shuts again at the return stroke. In the ordinary construction, as the disc drops in the same place each time, it is soon cut away by the bars in the grid. To remove this disadvantage, Messrs. Evans and Sons fix a small brass collar, *a* (Fig. 360), in the centre of the disc, *b*, and place it on a spindle. Instead of the passages through the grid being vertical, they are placed at an inclination, with the result that the water flows obliquely, and turns the rubber disc slightly at each stroke, causing it to drop in a different place each time. In their later construction of valve, the holes through the seat are made vertical, but the disc has teeth cut all round its circumference, such teeth being inclined; the action is exactly the same as in the former case, but the cost has been reduced. Such a valve is superior to a metal one up to certain pressures, especially where the water is gritty and dirty.

For heavy pressures, nothing gives better results than the Cornish, or double beat, valve (Fig. 361). These have been applied to pumps 9 in. diam., working under 700 ft. head, and have given every satisfaction. For larger pumps, instead of employing one valve, which would be very unwieldy and often get broken, multiple valves are used, that is to say, several double beats are arranged in a cluster. At the Bradley pumping engine, where the plungers are 27 in. diam., there are seven such valves working on gutta-percha beats in each clack box.

Quadrants.—For any type of horizontal engine fixed at the surface, quadrants have to be employed to change the direction of motion. If two lifts are used, quadrants are placed on opposite sides of the shaft, and so connected that one is making the up stroke, while the other is making the down stroke. In such case, the quadrant consists simply of an L-piece, as one balances the other; but where only one lift is employed, the quadrant is made of ⊥-shape, and a balance weight placed on one end. Instead of using wooden quadrants, wrought-iron or steel girders are common.

Suspended Lifts.—When water is met with in sinkings, even in small quantities, pumping has to be resorted to, owing to the limited space. This is not only a difficult but a very expensive operation. With the ordinary spear rods and engine at the surface, there are several methods for dealing with pumps during sinking, which may be divided into two distinct types: (*a*) The trees may be permanently fixed in the shaft as sinking proceeds and pipes added above the working barrel; such system requires a telescopic suction, or a telescopic pipe above the working barrel, and owing to the difficulty of securing the lower part of the pipes, is not to be preferred to (*b*) where the lift is slung by ground spears, and pipes added at the top of the lift.

FIG. 362.



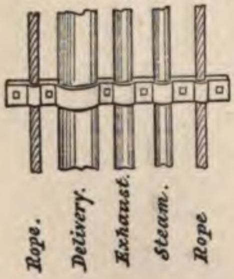
With this suspended lift the first thing to do is to make one part of the shaft into which the suction pipe is dipped lower than the other. An ordinary snore-piece is employed, *a* (Fig. 362), above which the clack-piece is attached, followed by the working barrel and rising main until the surface is reached. Sometimes projecting pieces are cast on each side of either the suction or clack-pipe, but a commoner plan is to fix two wrought-iron glands, *c*, underneath a flange. These glands receive the wrought-iron ends of the ground spears, *d*, which are secured in their place by cotters. These ground spears consist of two pieces of timber, passing down each side of the pump, and they carry at their upper ends pulley blocks, *e*, which are connected to similar pulleys, *f*, at the surface, and with the aid of ropes, the whole set can be lowered or raised as necessity requires. For additional security, other wrought-iron glands are added, which not only steady the lift, but strengthen the spears. A front bearer, or collar ring, *g*, is also fixed to steady the pump, and prevent any movement, which would be likely to take place through the up-and-down motion of the pump rods. Other cross-pieces, *b*, are placed to serve as guides for the spear rods. The ropes from the pulleys on the ground spears are wound on small crab engines at the surface. Pipes are added at the top as required.

The height at which the working barrel can be fixed above the water depends on several circumstances. Theoretically, the distance is 34 feet, because the pressure of the atmosphere will balance a column of water of that height. There are, however, several disturbing causes. The joints are never perfectly air-tight. There is also a certain amount of friction between the water and the sides of the pipe, which increases if bends are present. In actual practice from 27 to 30 feet is about the limit.

Such lifts are expensive both in first cost and in maintenance. To a great extent they have been superseded by direct-acting steam pumps slung in the shaft. The types of pumps employed are described a little further on. Three ranges of pipes are required—steam, exhaust, and rising main, all of which are usually of wrought-iron. The steam-pipe is supplied with a sliding joint, and a sliding suction has also to be employed, as the whole arrangement is only moved bodily about every 15 to 18 feet of sinking.

At Denaby Main Colliery, Yorkshire,* the pumps were suspended by two ropes worked by a steam crab, and the steam, exhaust, and delivery pipes were all clamped together and fastened to the ropes. The clamps were formed of two pieces of iron about 4 in. by 1 in. (Fig. 363), bent and curved to fit the pipes and ropes, and bolted together between each pipe. With this arrangement nearly 100 yards was sunk in one lift, but as this was

FIG. 363.



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* Brit. Soc. Min. Stud. xiv. 56.

not sufficient to get through the water, a tank was placed about 60 yards from the top.

At Canklow Sinking, Yorkshire,* a large quantity of water was successfully dealt with by pulsometers, which were all of No. 10 size, and capable of pumping 50,000 gallons of water per hour. They were suspended on one side of the shaft by heavy chains, to which the steam and delivery pipes were clamped as at Denaby Main Colliery. At a depth of something under 30 yards, which is the limit of the pulsometer's power, a tank was fixed in the shaft, and a man stood on a platform adjoining, to regulate the flow of water and see that the two lifts kept pace with each other.

FIG. 364.

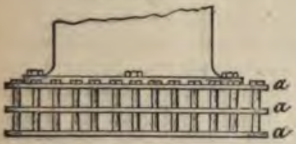
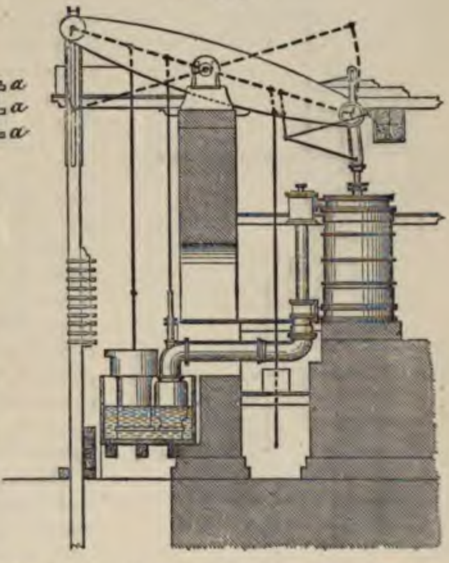


FIG. 365.



At the worst period, 150,000 gallons per hour were pumped with two lifts of three pulsometers each, arranged one above the other.

With an ordinary cast-iron snore-piece, breakages through shot firing are common. At Canklow a very excellent form of wind-bore was employed. It consisted of three wrought-iron plates (*a a a*, Fig. 364), the bottom one blank, the other two with a hole the size of the suction pipe through them. The lower flange of the cast-iron pipe was bolted to the top plate, and the three flanges were fastened together by a large number of small bolts, covered with iron ferrules, which being loose, withstood the shots, the whole forming a grating or cage.

Cornish Pumping Engines.—This type of engine, which is still largely employed for pumping operations, is illustrated in Fig. 365. It consists of a single cylinder, with its piston-rod connected to one end of a beam, the pump rods being attached to the other. It is a single acting engine, steam being admitted to the upper surface of the piston, causing the engine to make its in-stroke. An equilibrium valve is then opened, and steam passes to the lower side of the piston; the pressure is then equal on both sides. The weight of the pump rods causes the outward stroke. Communication is now opened between the lower side of the piston and the condenser, a vacuum formed, and steam re-admitted to the upper side of the piston. This engine was designed by Watt, and remains at the present time as he left it. The valves are opened and closed at the proper time by tappet rods, regulated by a cataract. Any number of strokes per minute can be obtained, although from the massiveness of the machinery, speed must necessarily be slow; in addition, a pause is made between the successive strokes, during which the valves, or clacks, have time to close, thus reducing any chance of shock. It is a large piece of machinery, very expensive in itself, and also to work, but when once in operation requires little attention, has a very high efficiency, and its wearing capacity is almost unlimited.

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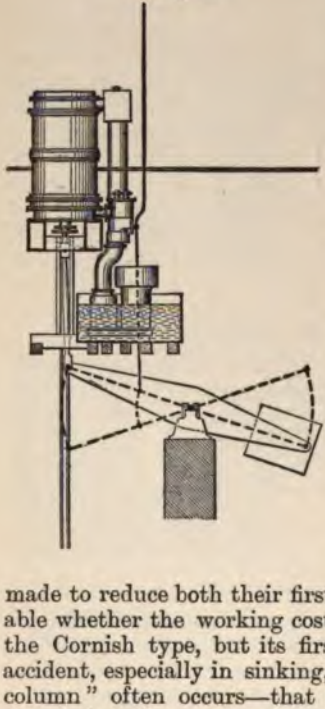
* Brit. Soc. Min. Stud. xiv. 52.

FIG. 366.



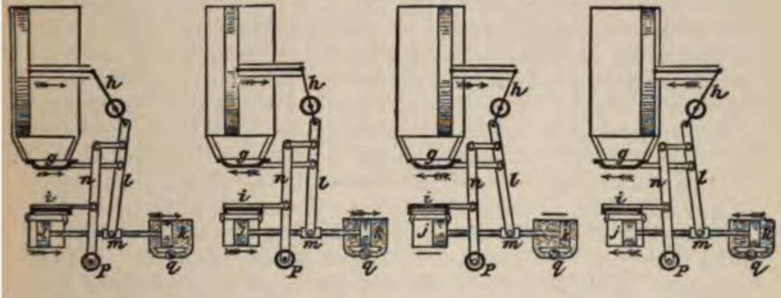
Bull Engine.—To reduce the cost of the machinery and erections, the Cornish Bull engine (Fig. 366) is often employed. In it the cylinder is placed directly over the shaft, and the piston rod connected to the spear rods. It works in exactly the same manner as the Cornish engine.

Davey Differential Engine.—Pumping engines have frequently been called "profit eaters," and attempts are always being made to reduce both their first and working cost. It is questionable whether the working cost of any engine is less than that of the Cornish type, but its first cost is great, and it is liable to accident, especially in sinking, when what is known as a "riding column" often occurs—that is to say, some obstruction gets in one of the valves in the clack; the whole weight of the column of water is thrown on the engine in the return stroke, and the load acts in conjunction with the steam pressure, instead of opposing it. In nine cases out of ten this means that something has to break, although to reduce the risk, stops, previously alluded to, are fixed at intervals, to prevent the engine going too far either on its out stroke or on its in-stroke.

To remove the danger Mr. Henry Davey has designed a gear, whereby a differential motion is communicated to the slide-valve which is connected to a lever, one end of which is worked by the engine piston, while the other receives an independent motion from a subsidiary piston controlled by a cataract. The action of the gear will be readily understood from Figs. 367–370, and the following description given by Mr. Davey.* The diagrams are not drawn to a scale, but clearly show the action of the gear.

The main slide-valve, *g*, is actuated by the piston-rod through a lever, *h*, turning on a fixed centre, which reduces the motion to the required extent and reverses its direction. The valve-spindle is not coupled direct to this lever, but to an intermediate lever, *l*, which is joined to *h* at one end, while the other end, *m*, is joined to the piston-rod of a small subsidiary steam cylinder, *j*, which has a motion independent of the engine cylinder, its slide-valve, *i*, being actuated by a third lever, *n*, coupled at one end to *l*, and moving on a fixed centre, *p*, at the other end. The motion of the piston in the subsidiary cylinder, *j*, is controlled by a cataract cylinder, *k*, on the same piston-rod, by which the motion of this piston is made uniform throughout the stroke; the regulating-plug, *q*, can be adjusted to give any desired time for the stroke.

FIGS. 367, 368, 369 AND 370.



The lever, *l*, has not any fixed centre of motion, as its outer end, *m*, is joined to the piston-rod of the subsidiary cylinder, *j*; the main valve, *g*, consequently receives a differential motion, compounded of the separate motion given to the two ends of *l*. If this lever turned about a fixed centre at the end, *m*, steam would be cut off in the engine cylinder at a constant point in each stroke; but as the centre of motion at the end, *m*, shifts in the opposite direction with the movement of the piston, *j*, the point of cut-off also moves, and is dependent on the position of the subsidiary piston at the moment when the slide-valve closes. At the beginning of the engine-stroke, the subsidiary piston is moving in the same direction, as shown by the arrows in Fig. 367, and in the instance of a light load, as illustrated in Fig. 368, the engine-piston, having less resistance to encounter, moves off at a higher speed, and soon overtakes the subsidiary piston moving at a constant speed under the control of the cataract; the closing of the main valve, *g*, is consequently accelerated, causing an earlier cut-off. With a heavy load, as in Fig. 369, the engine-piston, encountering greater resistance, moves off more slowly, and the subsidiary piston has time to advance further in its stroke before it is overtaken, thus retarding the closing of the main valve, *g*, causing it to cut-off later. At the end of the engine-stroke (Fig. 370), the relative positions become reversed from Fig. 367, in readiness for the commencement of the return-stroke. A retarding-gear is also applied, by means of which any pause that is required between successive strokes is easily obtained.

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* Inst. Mec. Eng., 1874, p. 261.

It is now many years since this gear was brought out, and long experience has proved its perfect reliability. Opinions differ as to the relative economies of the compound engine, with which this arrangement is connected, and that of the Cornish engine; but every one is agreed on the merits of the valve-gear, and it is becoming quite common to find it applied to the Cornish engine. Mr. Davey mentions an instance during sinking operations where the bottom-clack failed, and 90 yards of 18-inch column was riding on the bucket, and the engine continued working without any injury whatever. The total weight on the engine in the outward stroke was 7 or 8 tons, and in order to save the cylinder covers from being carried away, steam had to be admitted on the opposite side of the piston, reversing the ordinary working of the engine, and forming a cushion in front of the piston. This was entirely accomplished by the automatic action of the differential valve-gear.

Direct-acting Steam Pumps.—With any type of engine fixed at the surface the first cost is great, both for the engine itself and for its pit work. As considerable power is required to lift the great weight of rods hanging in the shaft, the engine has to be made larger than if such were absent. It has consequently become common, instead of employing such type of engine, to fix the pumps at the bottom of the shaft and force the water to the surface. The disadvantages here are—conveying steam underground, the difficulty of dealing with the exhaust-steam, and the liability for the pump itself to be "drowned," if the lodge, or sump-room, is not large.

The objections to introducing steam are here more than counterbalanced by the convenience of using the pumps, for their portability and the ease with which they may be worked is considerable. The exhaust steam, except with the larger pumps, can be got rid of by several devices. The liability to drowning can, to a certain extent, be avoided by fixing the pump in a special chamber, and only allowing as much water to pass into it as the pump can raise. This is usually done by a self-acting tap and ball arrangement.

Such pumps can be applied to lifts of a thousand feet, as the water is always flowing in the same direction, the movement during the reversal of the stroke being kept up by an air reservoir. The cost is low, breakages are rare, and the space occupied by them in the shaft is small. To lessen the difficulty of working the engine and keeping the room for it open, they are constructed long, narrow and low.

As with the other type, they are capable of being divided into two classes—bucket and plunger—and in addition, may be single and double acting. For clean water, the bucket pump with cup leathers is the best up to 400 to 500 ft. head, as the packing is easily replaced—any ordinary mechanic can do it—and its cost is less to commence with. For gritty water and high lifts the plunger types are preferable, as they are outside-packed, and any leakage is easily detected. Double acting pumps are certainly preferable to single acting ones. The latter only deliver water at each alternate stroke; their capacity is half that of a double acting one, and the column of water is brought to rest after each stroke, and has to be started again. In all cases, the stroke should be made as long as possible, as to obtain a given piston speed fewer strokes are required; the direction of motion is not changed so often, there is less wear and tear on the valves, and less shock to the different parts.

Among the many excellent pumps before the mining public, those of Messrs. Evans & Sons are in great favour. After considering several types, the author adopted those of Messrs. Evans' for his work. They are strong, well-designed machines, perform the work they are stated to do, and are easily managed by any ordinary attendant. They will restart themselves if stopped by want of steam, and require little supervision. It may appear invidious to single out one particular firm, but this is done because it is impossible to give descriptions of even a portion of the many pumps which are at work, to which the remarks made above may apply equally well.

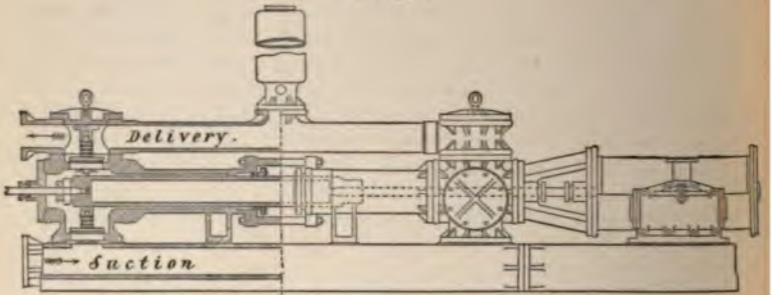
The steam end of Evans's Cornish pump consists of an ordinary piston fitted with Tonkin's valve, which is a steam-moved one, consisting of a smaller plunger inside a larger one, the latter carrying a common slide-valve. The steam-chest is placed on the side of the cylinder, and the bottom of the steam-port on the same level as the bottom of the cylinder; the whole of the condensed steam is carried out at every stroke of the piston, and the necessity for drain cocks avoided. There is no extraneous gear whatever; the pumps will start at any point of the stroke, there being no dead centre, and they can be worked by compressed air. The double acting plunger pump, with the pump-end half in section, is shown in Fig. 371.

All the pump parts are of cylindrical form, and the various portions are so arranged that they may be renewed without necessitating an entirely new pump. The valve-boxes are constructed to work against very heavy pressure, every valve is easy of access, and may be readily got at and renewed when required.

With the ordinary form of direct acting steam pumps, the motion is a purely reciprocating one. To make them work more smoothly and regularly, and also, perhaps, with more economy, fly wheels are added; such type lose the advantage of compactness, which is so valuable for underground use.

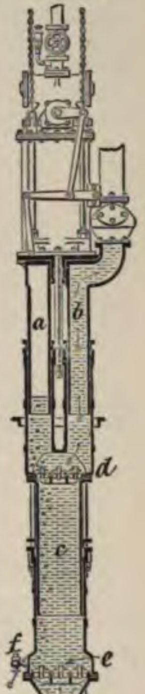
Worthington Pumps.—In this type, two pumps are placed side by side, the valve of each cylinder deriving its motion through levers, &c., coupled to the piston-rod of the opposite cylinder. When the one piston has nearly completed its stroke, the piston of the second cylinder is put into motion, and in turn gives effect to the slide valve and piston of the first cylinder. The great advantage is, that as the second piston starts to move, just at the moment when the first piston is completing its stroke, a steady and uniform flow is obtained in the delivery main. The column of water is never entirely stopped, and any recoil or shock is prevented. As one or other of the steam valves is always open, the pump will start at any point in the stroke. At the present time every one is manufacturing the duplex pump, and they are rapidly replacing the single cylinder form. For heavy pressures, they are, undoubtedly, superior to all others. They are open to the objection that if one pump meets with an accident, both become useless. Messrs. Evans have recently patented a duplex arrangement of their Cornish steam pump, each of which has Tonkin's valves, and can be worked independently of the other in case of break-down.

FIG. 371.



Pumps for Sinking.—Any well constructed pump can be used during sinking, but special types are manufactured for this purpose. Messrs. Evans construct one in which two rams are placed in the same straight line as the steam cylinder, which is of the ordinary pattern. The lower pump-ram is twice the diameter of the upper one, and only one suction valve is used. All the water first passes under the lower ram, which on its downward stroke delivers half the water into the rising main, and half into the upper end of the top plunger. When the rams rise, the lower one sucks in water, and the upper one delivers that water which has passed into it during the downward stroke. An air vessel is placed in the vertical delivery pipe similar in construction to Fig. 375.

FIG. 372.

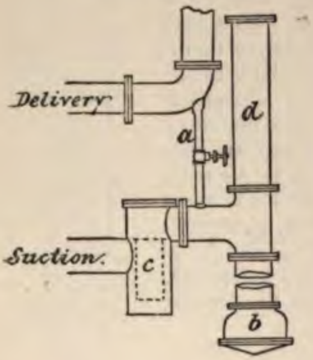


At Denaby Main Colliery a special type of pump was designed by Messrs. Bailey & Co., which consisted of three hollow plungers. The upper pair (*a* and *b*, Fig. 372) are stationary, and over them slide barrels, which are connected to the steam piston. From the lower end of these barrels projects the bottom plunger, *c*, which works into the third barrel, together with the two stationary plungers, and is secured by means of connecting rods to the steam cylinder; thus, there are two smaller barrels in connection with the larger ram, moving between the larger barrel connected with the smaller rams. A series of valves, *d*, constituting the delivery valves, are placed in the junction between the smaller barrels and the large ram, while the suction valves, *e*, are placed at the bottom of the large barrel.

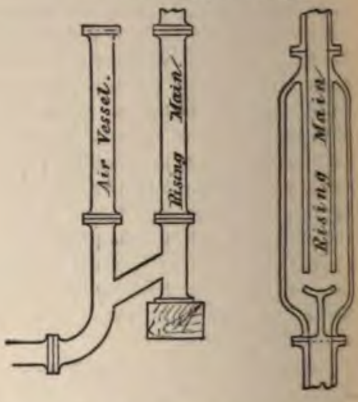
As the bottom plunger rises, the water follows it into the lower barrel, while at the same time the water in the upper hollow plunger is forced into the rising main. On the down stroke, the water in the lower barrel is forced through the lower plunger and valve into the upper barrels and plunger, and thence into the rising main; the discharge of water is therefore continuous. One of the upper plungers, *b*, is open at the top, and forms the discharge orifice for the water; the other, *a*, is closed, forming an air vessel, which is kept continuously charged with air, as a suitable snifting valve, *f*, is fitted to that side of the pump and below the discharge valves. It permits a small quantity of air to be taken in with every upstroke of the pump.

Arrangement of Supply Pipes, &c.—For successful working, a great deal depends on the arrangement of the suction and delivery pipes. The bends should be made as large as possible, and suitable air vessels are a necessity. Perhaps the best arrangement is that shown in Fig. 373. The suction pipe is attached to the end of the pump, and its lower length is provided with a foot valve, *b*, which always keeps the pipes and cylinder charged with water, and prevents the pump, on being started, from having to free both itself and the suction pipes from air. For gritty water, a strainer, *c*, is introduced in the suction pipes, and serves to prevent any coarse matter passing into the pump. A retaining valve should be placed between the end of the pump and the commencement of the delivery main, so that when any repairs are necessary, the pressure of water is kept off the pump. For charging the suction if at any time it loses water, a short length of pipe, *a*, with a suitable valve is inserted between the suction and the delivery pipes, of course, beyond the retaining valve. Where the suction pipe is long, it is just as necessary that an air vessel should be placed on it as on the delivery side. This is best done by carrying the suction pipe upwards and introducing a tee-pipe, *d*. This chamber can easily be extended by adding ordinary pipes and putting a blank flange at the top.

FIG. 373.



FIGS. 374 AND 375.



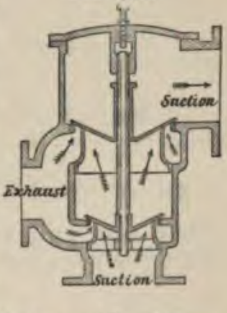
Air Vessels.—Direct acting steam pumps always work better with air vessels, although their utility is much questioned. Water being an incompressible fluid, some elastic medium has to be introduced to resist the shocks due to stopping and starting the column. Sometimes a pump works just as well (or rather as badly) with an air vessel as it did without one, but this is not the fault of the air vessel; it is more probably due to its improper position, insufficient size, and lack of attention. In the first place, the air vessel should be so situated that the air in the water tends to come back into it and not to flow past it. A very good rough arrangement is shown in Fig. 374, but, perhaps, the best is Fig. 375, where all the water has actually to flow right through the air vessel.

Then as to its size. What may appear to be a large chamber is fitted on to a pump, but it must be remembered that it is only charged with air at atmospheric pressure. With a lift, say, 300 feet, the pressure per square inch would be roughly 150 lbs., and immediately the pump starts to work, the water will compress the air in the air chamber with this pressure, and necessarily reduce its bulk; therefore instead of having, say, 10 cubic feet of air in the chamber, the volume under the above load is reduced to 1 cubic foot. It is also suggested that the air enters into mechanical combination with the water under this heavy pressure, just in the same way as it does in mineral waters, and that, sooner or later, unless it is attended to, the air chamber gets completely filled with water.

Neglect of counteracting these causes has in many cases made air vessels quite useless, and has given them a bad name, but with proper attention they will do everything that is claimed for them. They never work well, unless means are adopted to keep them properly charged with air, and the air so introduced should be above atmospheric pressure. The better plan, although it entails a little expense, is to employ a small force pump, worked by the piston-rod of the pump, which delivers a small quantity of air into the air vessel with each stroke.

Condensing Arrangements.—Where the diameter of the steam end is not double that of the water end, the exhaust steam can be easily got rid of in several ways. If the steam end is large, and the pump end small, the volume of exhaust steam is so great that the water is heated too much. Often the exhaust is turned into the suction pipes simply with ordinary pipe connections; but a far more successful arrangement is Holman's condenser, as applied by Messrs. Tangyes to their steam pumps (Fig. 376). A vacuum of from 8 to 10 lbs. is easily obtained, and back pressure removed. The apparatus consists of one or more double-beat valves, and the steam is introduced in annular streams to meet the suction water passing to the pump.

FIG. 376.



A condenser, acting in a very similar manner, is made by Messrs. Hayward, Tyler & Co. The aim of this appliance is to distribute the steam as much as possible in order that a large surface may be operated upon, and the condensation be correspondingly rapid. Where such appliances are used some valve has to be introduced, to allow the exhaust steam to be turned into the atmosphere whenever required. When the pump is first started, before the pipes are thoroughly filled with water, some such device is absolutely necessary. Any ordinary two-way valve will perform the operation.

Calculations as to the Size of Pumps.—The size of a pump to perform a certain amount of work is easily obtained by a simple method of reasoning. As an illustration of how such is done an actual example is given. At a colliery under the author's charge, water was raised by winding it in a tank; and by measurement it was found that, after allowing for slip, 10,000 galls. an hour had to be dealt with, or 166 galls. per minute. The first point to decide is the piston speed; many authorities say that this may be from 200 to 300 feet per minute. There is no doubt that such velocity can be used, but no pump makers, who, after all, are the best judges of the capacities of the machines, would recommend such speed for regular working. By common consent, a good and safe velocity may be taken at 100 ft. per minute. If 166 galls. have to be delivered every minute, and the piston speed be 100 ft., 1.66, or, say, 1.7 galls. will be delivered for each foot the pump works, if it is a double-acting one.

One gallon of water contains 277.25 cubic inches, therefore 1.7 gall. × 277.25 = 471.325 cubic inches of water have to be delivered for each foot the pump works.

$$\therefore \frac{471.325}{12} = 39.277$$

is the area in sq. inches of the required water column.

If the piston-rod of the pump is put at 3 in. diameter, its area will be 7.068 in., and this added to the area of the water column makes the area of the required plunger to be :—

$$39.277 + 7.068 = 46.345 \text{ sq. in.}$$

$$\therefore \text{ diameter of required plunger } \sqrt{\frac{46.345}{.7854}} = 7.68 \text{ in.}$$

The height to which water had to be lifted was 400 ft.; the pressure per sq. in. will, therefore, be :—

$$400 \times .433 = 173.2 \text{ lbs. } \therefore \text{ total pressure} = 39.277^{*} \times 173.2 = 6802.6 \text{ lbs.}$$

The steam pressure available was 60 lbs. per sq. in. The area of the steam cylinder, therefore, should be :—

$$\frac{6802.6}{60} = 113.38 \text{ sq. in.}$$

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* The pressure only acts on that part of the plunger surrounding the piston-rod, not on the rod itself.

One half of this area should be added for frictional resistance, &c., making the area 170.07 sq. in.

$$\therefore \text{diameter of steam cylinder} = \sqrt{\frac{170.07}{.7854}} = 14.743 \text{ in.}$$

or practically 15 inches.

From these results a pump was put to work, having a steam cylinder 16 in. diameter, and $7\frac{1}{8}$ in. rams, and has dealt with the quantity of water it was intended for.

In determining the quantity of water a pump of a given size will deliver, the converse of the preceding calculations can easily be made. When the piston speed is known, all that has to be done is to find the area of the rams, remembering that the area of the piston-rods must be taken out, as the water cannot occupy the space that they take up in the pump chamber.

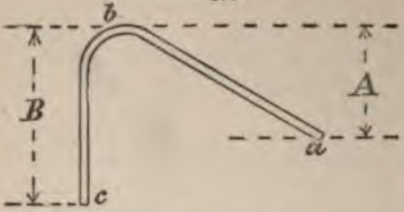
The quantity so found is the theoretical one, but is never reached in practice, owing to the occurrence of what is known as "slip." Neither the suction nor delivery valves can be instantaneously opened or closed, and, as a result, the piston does not discharge its theoretical volume at each stroke; a certain quantity is forced back into the suction during the delivery stroke, and another quantity escapes back into the pump-chamber on the return stroke. The amount depends entirely on whether the pump is in efficient working order or not. With the best constructed varieties in good order, the loss or slip will not amount to more than 2 per cent., but it may increase from that to anything if the valves are worn, or if an obstruction gets beneath them and prevents their closing.

Effect of Acid Water. — Water containing sulphates and chlorides has a most injurious effect on the working parts of pumps. Even when present in small quantities their influence soon makes the working parts rough, which either cuts away the bucket leathers or grooves the plungers. Free sulphuric and hydrochloric acids are contained in many mine waters, and are specially objectionable. To prevent this action the working parts are generally lined with gun-metal with satisfactory results. It is expensive, but there is no other alternative.

Draining Deep Workings.—If the shaft is at the lowest point the water may easily be conveyed from the working places to it and raised to the surface, but if the shaft is on a higher level than the workings the problem becomes a far more difficult one. With small quantities, the common way is to load the water into special tubs and convey them to the shaft in the same manner as the mineral, or hand-pumps can be employed. Both of these operations are very costly.

If the height to which the water has to be lifted is not very great, large quantities can be removed from deep workings by the use of a syphon, the principle of which is shown in Fig. 377. If the tube, *a b c*, is filled with water and open at both ends, the water naturally falls out of the end, *c*, which is the lowest, and creates a vacuum at the point, *b*. Now if the end, *a*, be connected with a reservoir of water the pressure of the atmosphere at that point will force water along *ab* to fill the vacuum, and a constant flow will pass from *a* to *c* under certain conditions. One condition is that the vertical height from *a* to *b*, or the height A, must not be more than that which the pressure of the atmosphere will supply. This theoretical height is never reached, owing to the friction of the water in the pipes and the resistance caused by the introduction of certain valves which are necessary for the successful working of the syphon. Practice proves that it cannot with safety be more than 27 ft. The other condition is that the discharge orifice must be lower than the inlet; it is also advisable that the gradient should be as uniform as possible, or air will collect in the bend, and the syphon cease to work. Indeed, where the pipes are undulating, as they sometimes have to be, discharge cocks must be placed at each bend in order that the pipes can be always freed from air. The discharge orifice should be as far below the inlet as is possible, for the velocity of efflux is represented by the pressure B—A.

FIG. 377.



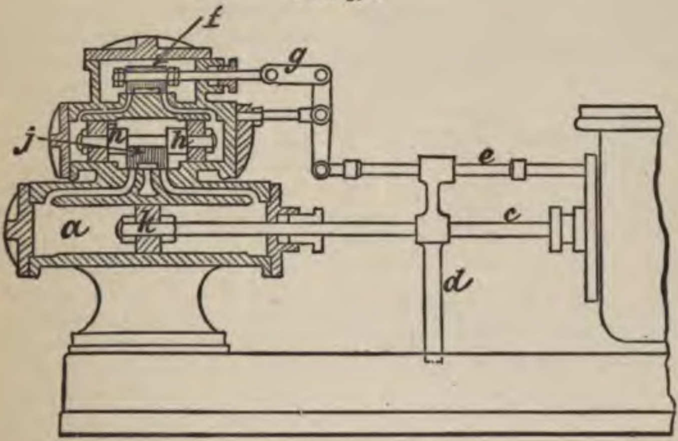
Where pumps are used, a small pipe should be led from the rising main into the syphon to allow water to be taken out and the syphon filled, if any leakage has taken place. A clack of a very light construction should be fixed at the inlet end to prevent the water flowing out when not at work, and a tap should also be introduced in the drop-leg to regulate the flow.

If the height exceeds 27 ft. other means have to be adopted, the commonest of which is that where horses are used. a throw-pump being worked by bevel gearing. This is, perhaps, the most arduous work to which horses can be put, and they are unable to remain at it for any length of time; it is also slow and costly. The horses are soon worn out, and something else must be employed. If power transmitted by wire ropes passes the place where the pumps are situated, or any point near, it becomes a very simple matter to carry an off-shoot to a pulley, which then takes the place of a horse. The endless rope system is particularly suitable for such arrangement. A clutch can be fixed to the pump, which can be set to work whenever required.

Where compressed air is available, pumps can be driven by it readily and cheaply; several are designed which work very satisfactorily with such a power, and are capable of dealing with large quantities of water.

Hydraulic Power.—Where pumping appliances are fixed in the shaft, hydraulic engines are often employed to pump from deep workings into the sump, the power to drive them being obtained from the rising main of the pumps. Their action depends on the principle that a small quantity under heavy pressure is equal to a large quantity at a small pressure, or having a head of water of 600 or 700 feet in the rising main, a small quantity of this can be conveyed to the deep, and lift a larger quantity of water into the sump for a height considerably less.

FIG. 378.



A common construction of such engine is employed at Tees Hetton Colliery, Durham,* and is shown at Fig. 378. It consists of a motor cylinder of special design, provided with controlling valves, and connected through a strong base plate to the pump, which is of the ordinary type. The piston of the motor cylinder, *a*, is connected direct to the piston of the pump, *c*, and the latter is provided with a cross-head, *d*, which serves to actuate the tappets on the tappet-rod, *e*. The small auxiliary valve, *f*, is operated by the tappet-rod, *e*, through the lever and valve rod, *g*, thus admitting the drive water to either end of the piston, *h*, which, in its turn, engages the main slide valve, *j*, and admits drive water to the motor piston, *k*. The latter accordingly makes its stroke until arriving at the opposite tappet, when the motion is reversed. The exhaust water from the motor cylinder is discharged on the upper side of the delivery valves in the pump, and passes away to the main pumping engine. The controlling valves of the motor cylinder are composed of lignum-vitæ, as this wood requires no further lubrication than is afforded by the water. The pressure on the motor piston of the pump was roughly 230 lbs. per sq. in., and by means of this pressure, 7000 galls. per hour were forced to a height of 156 feet.

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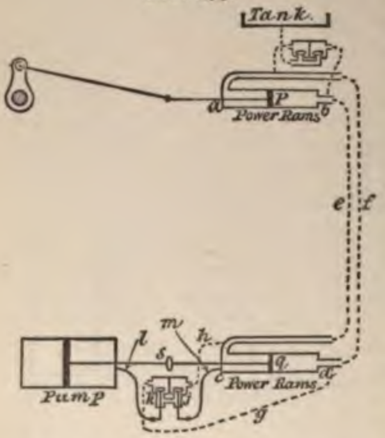
* Brit. Soc. Min. Stud xi. 132.

FIG. 379.



*Moore's Arrangement.**—An hydraulic engine of a totally different class is that designed by Mr. Joseph Moore, where two columns of water are substituted for the ordinary solid rods connecting the steam-engine to the pump. The action will best be seen from the diagrammatic representation (Fig. 379). A cylinder, *a b*, at the surface, having a piston *p* is driven in the ordinary way by a steam engine, and each end of this piston is connected to each end of a smaller cylinder, *c d*, situated underground, having a piston, *q*, and connected through a piston-rod to an ordinary double acting pump. The pipes and the cylinders are all full of water. When the surface piston *p* moves from *a* towards *b*, water is forced down the pipe *e* and moves over the piston *q* towards *d*; when the piston *p* reverses its motion, the piston *q* is also reversed.

The success of the appliance is due to an arrangement whereby the stroke of the rams is adjusted, as without some such appliance, should there be any leakage in one of the power pipes, the plunger at the bottom would make a shorter stroke in one direction than in the other, and would work towards the end, and, unless there were some regulator, knock off the cylinder cover. It will be noticed that the pipe *g h* connects the two power pipes *e* and *f*. In this pipe are two valves, *j* and *k*, opening in opposite directions, the former closing against pressure from pipe *e*, and the latter against pressure from *f*. These valves are opened by tappets, *m* and *l*, set apart a few inches more than the length of the stroke. If the pipe *e* leaks, the piston *q* will not make as long a stroke as it should do, and stops short of *d*. In the return stroke, when the piston *q* has travelled as far as it safely should do, and before the piston *p* on the surface has completed its stroke, the projection *s* catches the tappet *l* and opens the valve *k*. The pressure of water in *f* is now free to lift the valve *j*, and to run into *e*, immediately equalising the pressure on both sides of the piston *q* and stopping it. The water displaced by the remaining part of the stroke of the piston *p*, passes through the valves from one power pipe to the other.

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* Min. Inst. Scot. xii. 168.

The power pipes are kept charged from a tank placed above the level of the highest point. There is a valve opening inwards on each of them, and when the piston *p* makes the return stroke, enough water is sucked in to make up any leakage. A considerable number of these engines are at work, and it is stated that diagrams taken from one working at the Shotts Iron Co.'s Collieries, Edinburghshire, show that 66.26 per cent. of the work shown in the indicator diagram of the steam-engine is got out of the pump.

Electricity.—The use of electricity in mines was first called into requisition for pumping, and by far the larger number of installations are still applied to such a purpose. An electric motor can be readily connected to a pump, either by gearing or belts. The convenience of electricity is such that in all installations of the last few years, scarcely anything else has been employed in pumping from deep workings. Innumerable instances could be quoted of its success, but for our purpose we may best refer to the first pumping plant and its additions, which were put down by Mr. Brain, at Trafalgar Colliery, Gloucestershire.* This commenced working in December 1882, and attained such success that three additional plants were erected in May 1887, and are now doing the larger part of the underground pumping.

The last installation consists of a double throw 9 in. plunger, by 10 in. stroke, situated 2220 yards from the generator, and 1650 yards from the bottom of the shaft; the pipe main is 7 in. in diameter, and at a maximum speed of 25 strokes, the pump lifts 120 gallons per minute, 300 ft. high. The current is conveyed to the motor by a copper conductor consisting of $\frac{19}{16}$ wire, insulated and carried on earthenware cups. The E. M. F. is 320 volts, and the current required is 43 ampères. The cost of the engine and the electrical plant was £644; the weekly cost for maintenance, including 15 per cent. for depreciation and interest on capital, is £7 17*s*. or .002*d*. per horse power per hour. The efficiency attained throughout was only 35 per cent., but the engine, which is an old one, loses 6.49 horse power, or 22 per cent. alone; excluding loss in the engine the efficiency is 45 per cent.

With the aid of accumulators, or secondary batteries, in which the current of electricity can be stored and carried about, small quantities of water at inaccessible points can be, and have been, dealt with in mines. These accumulators can be placed on a carriage and taken anywhere required. A small motor and pump on a second carriage are also arranged, and accompany the accumulators.

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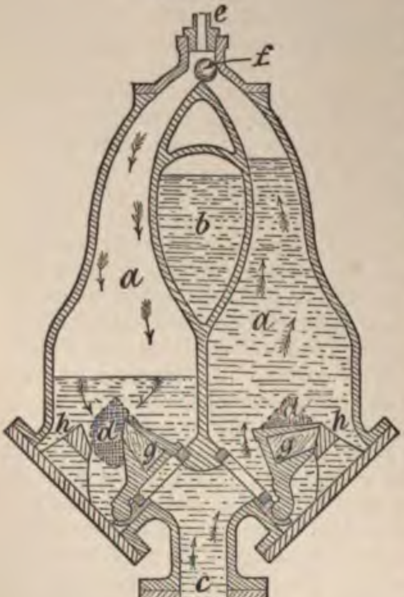
* Brit. Soc. Min. Stud. xi. 48.

Pulsometer.—When describing the methods of dealing with water during sinking, reference was made to the pulsometer, which is also largely employed for draining deep workings. It consumes a great deal of steam, but its advantage is that it will pump nearly everything that will go through the valves. No matter how gritty or dirty the water is, it works nearly as well as if it were quite clean. Its peculiarity consists in there not being any steam cylinder, piston, piston-rods, or bucket, as is usual in the ordinary form of pump. Its construction is shown in Fig. 380. It consists* of two pear-shaped water chambers, *a a*, the air chamber, *b*, the suction passage, *c*, and the delivery passages, *d d*, which communicate with the discharge pipe. Steam is admitted to either of the chambers, *a*, through the pipe, *e*, but the direction is controlled by a ball-valve, *f*, which is capable of oscillating, and closes each passage alternately; *g g* are the suction-valves, which are of the ordinary flap form, and are prevented going too far by the stops, *h h*. It should be especially noticed that the delivery passages, *d d*, commence in each of the water chambers just above the suction-valves.

FIG. 380.



The action of the apparatus is as follows:—When the two chambers, *a a*, are full of water, if steam be admitted through the opening, *e*, it will pass into that chamber which is not closed by the ball-valve, *f*, and rapidly depressing the water *without causing any agitation*, will force it through the delivery chamber, *d*, into the rising main. This action continues until the water is depressed to the top of the passage, *d*, when the steam attempts to rush through this opening, and in doing so violently agitates the surface of the water. Immediately this takes place, instant condensation follows, and a vacuum is produced in the chamber. This sucks over the ball-valve, and diverts the live steam into the other chamber, depressing in turn the water there. While this is going on the vacuum in the first chamber sucks up the water through the pipe, *c*, and lifts the suction-valve, *g*. When condensation takes place in the second chamber, as it will do as soon as the water is lowered to the top of the discharge orifice, *d*, the ball-valve is again sucked over, and live steam diverted into the first chamber. The suction-valve then closes, and the water is discharged as before; first one chamber and then the other is filled and emptied.

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* So. Wales Inst. xi. 85.

Dams.—It is often necessary to put in stoppings, called "dams," to prevent water passing from one part of the mine to another. On the Continent wooden dams are most in favour, while in this country masonry is generally employed. The advantages of the former are that if the wood is perfectly dry when put in, the moisture expands it and makes the structure more water-tight, and any movement in the surrounding strata is not so liable to dislodge or crack the wooden dam, as it is a masonry one. Owing, however, to the convenience and ease with which bricks can be obtained and put in position, their use is becoming common, even in districts where wood was formerly employed.

In putting in permanent dams the first thing is to select some spot where the strata is of an impervious character and quite free from cracks. Dams are invariably wedge-shaped, with the broader end towards the pressure. If this be heavy, two or three wedges are built, one against the other. In preparing the ground, nothing but the pick and chisel should be employed; the sides, floor, and roof are carefully dressed to the required shape, and covered with Portland or other cement, to obtain a hard and proper surface to receive the masonry. Good hard burnt bricks should be employed, and the lime should be of an hydraulic character.

To pass the water from one side to the other while building is going on, a pipe is invariably built through the lower part of the dam, this being fitted with a valve at one end, which can be closed when the work is finished. A second pipe of smaller dimensions is also built through the dam near the top, and its inlet end carried into a cavity in the roof, the object of this being to ensure the removal of the last trace of air from behind the dam, which is a point of the greatest importance. The water side of the dam is often covered with either tarred sheets or well puddled clay, either of which will preserve it, and prevent leakage should it become much cracked.

Bibliography.—The following is a list of the more important memoirs dealing with the subject-matter of this chapter:—

MIN. INST. SCOT.: *Some Practical Results of Hydraulic Pumping*, D. Johnstone, iii, 157 and vi. 112; *On the Sucking Power of the Common Pump and of some of the Shocks which occur in Pumping*, J. McCreath, iv. 239; *On an Improved Arrangement for Working Underground Pumps by means of Hydraulic Pressure*, Robert T. Moore, v. 290 and xii. 168; *Air Vessels*, Dugald Baird, x. 251; *Air Vessels*, Allan Andrews, xi. 113.

SOC. IND. MIN.: *Mémoire sur la nouvelle machine d'épuisement intérieure de Montceau-les-mines*, M. Audemar (2^e Série), i. 437; *Machines d'épuisement à l'Exposition de Paris* (1878), Ch. Buisson (2^e Série), viii. 801; *Note sur le nouveau balancier d'équilibre de la pompe du puits de l'Ondaine*, M. Griot (3^e Série), iii. 349.

SO. WALES INST.: *Pumping Arrangements at the Radstock Collieries, &c.*, J. McMurtrie, xi. 66; *A Short Description of the Pulsometer and Hydrotrope*, Hort. Huxham, xi. 85.

CHES. INST.: *Draining and Ventilating, &c., at Staveley Collieries*, Jos. Humble, ix. 31.

AMER. INST. M.E.: *The Worthington Compound Duplex Pressure Pump*, R. W. Hunt, iv. 317; *Pumping Engines*, John Birkinbine, v. 455.

FED. INST.: *Parker & Weston's Pump for Colliery Purposes*, G. B. Walker, ii. 11; *Pumping Appliances at Eltringham Colliery*, J. K. Guthrie, ii. 457; *Notes on an Electric Transmission Plant at East Howle Colliery*, H. Palmer, iii. 271; *The Pumping Appliances used in the Sinking Operations at Cadeby New Winning*, W. Henry Chambers, iii. 513.

N. E. I: *A Direct Acting Engine at Towneley Colliery*, J. B. Simpson, xv. 157; *On the duty of Cornish and other Pumping Engines for Mines*, J. B. Simpson, xix. 201; *The Difference between the Statical and Dynamical Pressure of Water Columns in Pumps*, E. Bainbridge, xxi. 49.

BRIT. SOC. MIN. STUD.: *Variation of Pressure in Pumps*, H. F. Bulman, iii. 107 and viii. 138; *Notes on the Erection of a Large Ram Pump*, E. F. Melly, viii. 40; *Electricity applied to Mining*, F. Brain, xi. 48; *Hydraulic Pumping*, W. Walker, Jun., xi. 132; *Electrical Pumping Plant at South Pontop Colliery*, J. R. Ritson, xiv. 82; *Some Methods of Draining Dip Workings*, H. F. Bulman, xv. 46.

CHAPTER XI.

VENTILATION.

Importance.—It is most important that mines should be properly ventilated. All coals give off, to a more or less greater extent, a quantity of deleterious gases, which have an injurious effect on the human life, even if they are not explosive. In addition the breathing of men and of other animals, and the burning of illuminants, render air impure. It, therefore, becomes necessary that a vigorous current of cool, fresh air should be circulated through the galleries and the working-places; indeed, General Rule I. of the Mines' Regulation Act, 1887, makes such a current compulsory, but even if such were not so, it really pays to have good ventilation, as men are not only capable of doing a greater quantity of work, but they do it with greater comfort and are far more contented.

The quantity of air required in a given mine depends principally on the volume of gases produced by the coal. The quantity of gas given off does not always increase as the workings become more extensive, as it principally depends on the area of freshly exposed coal surface. If bord and pillar working be adopted, a quantity of gas will be given off while the exploring work is being done, but as the pillars are large blocks of coal, up to 50 yards square or more, the comparatively narrow (2 to 5 yards) places driven to form the pillars, cannot liberate the whole of the gas. When the second or broken workings are proceeding, wider places are driven and the coal is got more easily, so that more coal is being worked per man per shift, and more gas is liberated. With long wall working, as the workings get more extensive, a greater area of face is opened out, and consequently more gas will be given off. The best plan is, therefore, to make the amount of air proportionate to the output and to increase the current, if exploratory work is proceeding. It is often stated that the amount of air passing should be regulated by the number of men employed. Of course, if the output increases, the number of men generally increases also, but the better plan is to be guided by the output, which is the practice of the Borinage district of Belgium, which is, probably, the most fiery in the world.

Gases met with in Mines.—Atmospheric air in its pure state is a mixture of two gases, nitrogen and oxygen, but, as generally found in Nature, it contains small quantities of another gas, carbonic acid, and of aqueous vapour. The oxygen is the life-supporting element, the nitrogen acting simply as a diluting agent. Dry air is composed of 79 per cent. by volume of nitrogen gas and 21 per cent. of oxygen.* In breathing, men and other animals take air into their lungs, and part of the oxygen combines with carbon, forming carbonic acid, whilst the nitrogen is unaltered; the same result follows the burning of lights.

Carbonic Acid is known to the miner as black-, or choke-damp, or stythe. Its presence is common, and is due to the combustion of illuminants, respiration of men and horses, combustion of blasting explosives, decomposition of pit timber, and often exudation from the coal. It is chemically composed of carbon and oxygen; its symbol is CO_2, and it has a specific gravity of 1.53. As it is considerably heavier than air, it tends to occupy the lowest part of the mine. In its pure state it has no colour, but has a peculiar sharp, but not sour, odour and taste. Its presence is manifested by its influence on the flame of a candle, as it will not support combustion. Its effect on human life is dependent upon the proportion present. Over 3 per cent. produces sleepiness, while with 10 per cent. the motion of the heart is temporarily suspended. On the Continent, outbursts of carbonic acid are frequent, and are in every respect similar to those of fire-damp. The blowers are generally found in the vicinity of faults. At Toulane Pit, Rochebelle, one blower filled 500,000 cubic feet of workings in less than ten minutes, and disengaged over 400 tons of coal.

Carbonic Oxide is variously known as carbon monoxide and white-damp. Its chemical symbol is CO and specific gravity 0.97. Luckily its presence is much less frequent in mines than black-damp, as it is far more poisonous than that gas. As little as 1 per cent. produces giddiness and faintness, while over 2 per cent. may cause death. Indeed, $\frac{1}{2}$ per cent. breathed for any length of time is fatal. Carbonic oxide is known by its sweet and delicate odour and deadly results. Candles burn well in this gas, if anything, a little brighter, although their flame is not elongated until $12\frac{1}{2}$ per cent. is present. It is produced by imperfect combustion, and especially by spontaneous ignition.

Sulphuretted Hydrogen is not found in large quantities. Its chemical symbol is SH_2, and specific gravity 1.17. It arises from the decomposition of timber in water containing sulphates in solution, or, to a smaller extent, from blasting, especially if inferior cheap gunpowder is employed. It has an injurious effect on life, does not support combustion, and burns with a blue flame. Its presence is immediately detected by a characteristic and offensive smell.

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* A table is given at the end of the chapter showing the specific gravities, molecular weights, &c., of the gases met with in mines.

Light Carburetted Hydrogen.—This gas, known as fire-damp, is the one commonly found in mines, and to which explosions are principally due. It consists, in the pure state, of carbon and hydrogen, its symbol being CH_4 and specific gravity 0.559. The fire-damp of the miner is, more correctly speaking, a mixture of several gases, the largest proportion being carburetted hydrogen. Other hydrocarbons, with hydrogen, carbonic oxide, oxygen, and nitrogen, are generally present, the quantities of such gases varying considerably in almost every colliery, and often in different districts of the same pit.

The coal itself is the principal reservoir of the gas, where it is held in the pores or cells in a state of more or less high tension. Different gases exuded from the coal have been described in Chapter II., where the phenomenon of "blowers" was also referred to. Blowers are a more or less steady discharge of gases from the coal, continuing for a long time. Where this discharge is a violent and sudden one of large quantity, only continuing a short time, it is known as an "outburst."

Carburetted hydrogen is colourless, and when pure is odourless, while fire-damp is often detected by its smell. This gas, if breathed in a pure state, would soon cause death; it quickly extinguishes flame or lamps if undiluted by air. When 3 to 4 per cent. is present in air, the gas can easily be detected by the elongation of the flame in a safety lamp. If 6 per cent. be present the flame is not only elongated, but a blue halo, or cap, appears above it. This halo is often of a brown colour, produced by the presence of carbonic acid gas with the fire-damp. With 7 to 8 per cent. the mixture becomes explosive, and flame is propagated through the contents of the lamp; with 10 to 12 per cent. the propagation is instantaneous and the explosion attains its maximum amount; with 20 per cent. the mixture no longer explodes, but instantly puts out any flame that may be brought into it.

After-damp.—Under this head is included all the products resulting from the ignition of an explosive mixture. When fire-damp is exploded, the carbon combines with the oxygen in the air, and forms carbonic acid, while hydrogen also combines with oxygen and forms aqueous vapour, leaving a large amount of free nitrogen without the corresponding amount of oxygen. Carbonic oxide is generally present in after-damp, and is always formed during the combustion of every explosive mixture containing carburetted hydrogen in which the proportion of air is less than 9.5 parts. Messrs. Atkinson* give an analysis of the after-damp gases of the Usworth explosion in 1885. The sample was taken from between two stoppings erected on the fifth and seventh days after the explosion, and contained 2.48 per cent. of carbonic oxide, and 4.54 per cent. of carbonic acid gas; it may be, however, that the presence of a fire beyond may have had some influence on the production of these gases, the proportions being unusually high.

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* *Explosions in Coal Mines*, London, 1886, p. 113.

The combustion of 1 cubic ft. of fire-damp renders about 40 cubic ft. of air unfit for respiration. If an excess of air or fire-damp were present before explosion, such excess would remain mixed with the after-damp after the explosion, but in no case can the after-damp gases contain more than one-third of their volume of unchanged air, or the explosion would not have happened. After-damp is sometimes responsible for more deaths than an actual explosion, as often all that escape the latter are suffocated by the former.

Coal-Dust.—The roadways of some mines contain accumulations of very fine coal-dust scattered over the timber and resting on the floor. Messrs. Faraday and Lyell, in a report on the Haswell Colliery explosion in 1844, were the first to demonstrate the effect these accumulations of dust may have in extending fire-damp explosions. Although several persons investigated the matter, it was not until 1876, when Mr. Wm. Galloway read his first paper before the Royal Society,* that general attention was directed to the important part that coal-dust plays in aggravating fire-damp explosions. Subsequent experiments by Mr. Galloway,† by several members of the North of England Institute,‡ a committee of the Chesterfield Institute,§ Sir F. A. Abel, and particularly by the Prussian Fire-damp Commission,¶ demonstrated that, under certain conditions, the presence of coal-dust in a fine state of division is a source of danger in dry mines in which blasting is carried on without special precautions.**

Upwards of 300 experiments were made by the Prussian Fire-damp Commission at Neunkirchen, near Saarbrücken, and it was considered that the following conclusions were warranted by the results obtained:††—

1. The presence of coal-dust in more or less abundance in the immediate vicinity of the working face, gives rise to more or less elongation of the flame projected by a blown-out shot, *whether small quantities of fire-damp be present in the surrounding air or not.*

2. (*a*) In the complete absence of fire-damp, the elongation or propagation of flame is generally of limited extent, however far the deposits of dust may extend in the mine-ways.

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* Proc. Royal Society, March 2, 1876, xxiv. 239.

† *Ibid.* xxviii. 437 and 490, and xxxvii. 42.

‡ N. E. I., xxv. 239, and xxviii. 85.

§ Vol. x., with appendixes.

Blue-Book, "Seaham Colliery Explosion," and Proc. Royal Institution, x., Part I. 1882.

¶ Translation by T. W. Bunning, N. E. I., xxxiv. 199 and 297.

** A complete review of the literature of the subject with extracts of the opinions held by English authors, is given by Mr. E. S. Hutchinson in paper entitled *Notes on Coal-dust in Colliery Explosions*, Amer. Inst. M. E. xiii. 253.

†† English Commission on Accidents in Mines. Final Report, 1886, p. 43.

2. (*b*) There are, however, certain descriptions of coal-dust which, if ignited by a blown-out shot, will not only continue to carry on the flame even to distances extending considerably beyond the confines of the dust deposits, but will also give rise to explosive phenomena or results, *in the complete absence of any trace of fire-damp*, which in character and effects are similar to those produced by some other dusts in air containing 7 per cent. of fire-damp.

3. (*a*) All the phenomena produced by the burning of and propagation of flame by coal-dust are intensified by the presence in the air of small proportions of fire-damp.

(*b*) Certain dusts which under favourable conditions appear to have the power of propagating flame to an indefinite extent in a dust-laden area, the air being free from fire-damp, will, if only sparsely suspended in air containing fire-damp in some proportion below 3 per cent., render such a gas-mixture susceptible of explosion by a blown-out shot.

4. Special experiments in which the branch gallery, described as opening into the main gallery near its extremity, was charged with a fire-damp mixture (retained by brattice cloth), demonstrated that a coal-dust ignition or explosion, developed in the complete absence of fire-damp, can communicate ignition to an explosive gas-mixture existing at a very considerable distance from the point of first ignition.

Special stress was, however, laid on the fact that the occurrence of a blown-out shot is indispensable to the production of any and all of the effects (of ignition, propagation of flame, or explosion) to which coal-dust can give rise; and Mr. Hilt emphasises the fact that the part played by coal-dust is not nearly so dangerous as it might appear from a superficial examination of the Saarbrücken experiments.

Messrs. Mallard and Le Chatelier, in a review of the work of the Prussian Commission,* consider the phenomenon of the ignition of coal-dust by a blown-out shot to be as follows:—In that part of the gallery reached by the powder-gases travelling at a high velocity and endowed with a high temperature, the dust is violently thrown into suspension and ignites. The gaseous mass thus ignited (considerably expanded by heat and increased by the partial distillation of dust that has been thrown into suspension by the mechanical effects of the powder-shot) expands into the gallery, and extends to a distance proportional to the mechanical effects of the powder-gases and to the ease in which the dust in suspension is distilled. The mechanical effect of this jet of flame on the dust in the gallery, situated at such a distance as to escape the initial action of the powder-gases, is small, and rapidly decreases until it is destroyed at a very short distance from the shot. They consider that the experiments of the Prussian Commission confirm these opinions, and also their previously expressed ones,† that the combustions of dusts are not, to speak exactly, explosions; that combustions only produce mechanical effects entirely insignificant for most dusts, and always much less than fire-damp explosions, even for most exceptional dusts; and that the combustion produced at any point does not extend indefinitely over the whole area covered with dust.

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* Ann. des Mines (8e Série), ix. 638. † *Ibid.* (8e Série), iv. 274.

On the other hand, the Royal Commission on Accidents in Mines[*] considered that the most emphatic refutation of Messrs. Mallard and Le Chatelier's conclusion, "that the influence of fire-damp upon the combustibility of dusts, if not altogether *nil*, is at least much slighter than was at first believed," and confirmation of the established facts which it combated, was furnished by the Saarbrücken experiments, and, after a review of the whole subject, considered that the following facts relating to the part played by dust in coal-mine explosions may be regarded as conclusively established:—

1. The occurrence of a blown-out shot in working places *where very highly inflammable coal-dust exists in great abundance* may, *even in the total absence of fire-damp*, possibly give rise to violent explosions, or may at any rate be followed by the propagation of flame through very considerable areas, and even by the communication of flame to distant parts of the workings where explosive gas-mixtures, or dust-deposits in association with non-explosive gas-mixtures, exist.
2. The occurrence of a blown-out shot in localities *where only small proportions of fire-damp* exist in the air, *in the presence of even comparatively slightly inflammable, or actually non-inflammable but very fine, dry and porous dusts*, may give rise to explosions, the flame from which may reach to distant localities where either gas accumulations or deposits of inflammable coal-dust, may be inflamed, and may extend the disastrous results to other regions.

That the above conclusions are true is now generally admitted, and the importance of adopting some effectual means for dealing with dust-deposits becomes self-evident when it is remembered that the most practised observer cannot detect gas in the air-currents with safety-lamps when the proportion present does not exceed 2 per cent.

It is, however, contended, more prominently by Mr. Galloway and Messrs. Atkinson,[†] that coal-dust plays the principal part in colliery explosions, and that fire-damp must be relegated to a secondary position. The chief argument in favour of this view is that explosions are so often confined to the intake air-ways and not to return air-ways. The intakes are where dust collects owing to the haulage of coal, while the returns are those along which gas is carried off. It is also contended that gas explodes equally in all directions, while many explosions in mines do not seem to pass into all the routes equally open to them, but follow certain definite paths, such as intake airways where gas is absent but coal-dust present. An explosion that took place in a coal-hopper at Brancepeth Colliery, Durham, where no gas could be present, is also quoted as an argument in favour of this theory.

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[*] Final Report, p. 47.

[†] *Explosions in Coal Mines*, London, 1886.

This hopper was used to store coal in for the use of the coke ovens. It was being cleaned out, when the fine dust took fire at an open torch lamp. Several men were severely burnt and three lost their lives. It may, however, be taken more as an instance of ignition than of explosion, as, although several windows existed in the hopper, none of the panes of glass were blown out, although they were much cracked by the intense heat. Only one sheet of corrugated iron was burst off the box, and this was not blown away, but was simply dislodged and fell to the ground.*

The theory is supported by the fact that explosions happen in flour mills, and in the drying chambers used for the preparation of brown coal for the market. It has also been proved by large explosions which have taken place in flour mills at Annapolis, U.S.A., that in the entire absence of inflammable gas, the explosion beginning in a distant portion of the works may be carried through the entire building. It is also possible, experimentally, to obtain explosions with air and lycopodium, simply with the lycopodium lying on the floor and not forming a thick cloud.

The great argument against coal-dust being the principal agent in coal-mine explosions, as pointed out by the Royal Commission on Accidents in Mines,† is the fact that, if it were so, *every* blown-out shot occurring in a *very* dusty and dry mine should actually be attended by a more or less disastrous explosion or conflagration; and that, looking therefore to the enormous amount of powder expended in shot-firing in this and other countries, and to the not inconsiderable proportion which blown-out shots must constitute, in many localities, of the total number of shots fired, disastrous coal-mine explosions should be of more than daily occurrence, if this view were correct.

Messrs. Mallard and Le Chatelier maintain that all explosions of magnitude which have been solely attributed to coal-dust have occurred in mines in which fire-damp occurs; that the possibility of coal dust, *per se*, giving rise to an important explosion could only be established by the occurrence of an explosion in a mine in which the total absence of fire-damp can be absolutely demonstrated; and by the fact that lignite mines, which are generally very dusty, the dust being extremely inflammable, but which are at the same time almost free from fire-damp, have never yet been visited by accidents of this class.

In Chapter II. reference was made to the experiments of Mr. J. W. Thomas on the gases enclosed in coal. Dr. P. P. Bedson has conducted similar investigations on coal-dust ‡ and has established the point that some dusts give off considerable volumes of explosive gas at a comparatively low temperature. The enclosed gases in coal-dust resemble in many respects those which have been obtained from coal. The main points of difference to be noted are, first, the large proportion of carbon dioxide (CO_2) as compared with the amounts found by Mr. Thomas, and, second, the presence of olefines and higher members of the paraffin series of hydrocarbons.

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* Royal Commission on Coal Dust, First Report, p. 108.

† Final Report, p. 47.

‡ *A Contribution to Our Knowledge of Coal-dust*, N. E. I. xxxvii. 245.

In the final Report of the Austrian Fire-Damp Commission[*] it is stated that the experiments made confirm those of Neunkirchen with regard to the danger of coal-dust, but also show that the dangers are greater than have hitherto been admitted. First of all the Commission tested the different kinds of coal-dust so as to classify them according to their sensitiveness to ignition and their danger. As they considered that black powder and similar explosives are dangerous in fiery mines and that their use should be entirely prohibited, they confined their experiments to high explosives, especially dynamite No. 1. The experiments were made in levels, like the one at Neunkirchen. Each kind of dust that was used was also tested in order to determine the following facts concerning it:—

1. Percentage of volatile matter.
2. Hygroscopic moisture.
3. Percentage of ash.
4. Quantity of marsh gas in 100 grammes of dust.
5. Quantity of gas given out by 100 grammes of dust at 100° C.
6. Composition of gas given out by 100 grammes of dust at 100° C.

Instead of imitating blown-out shots, the experiments were mostly made with cartridges of dynamite lying loose, or with a slight covering of coal-dust. The coal-dust experiments were almost exclusively made without any admixture of gas. In one of the levels, 353 experiments were carried out and showed that many notoriously dangerous dusts were less inflammable than other less dangerous dusts. Coal-dusts were therefore classified into sensitive and dangerous kinds. To judge of their sensitiveness, the coal-dusts were all tested with the same charge of dynamite, viz.: 100 grammes (3½ ounces). The experiments showed that without any admixture of fire-damp, nearly all kinds of coal-dust were ignited by a cartridge of 100 grammes of dynamite lying loose. The following points were considered established:—

1. The degree of inflammability can scarcely be deduced from the chemical composition.
2. The texture of the coal is important. Hard compact coal will give less dust than crumbling friable coal. The fineness of coal-dust depends upon its texture.
3. The sensitiveness of a coal-dust, and as a rule, its danger, increase with its dryness.
4. The danger of a coal-dust appears to depend more upon its physical qualities than upon its chemical composition.

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[*] Schlussbericht des Centralcomités der österreichischen Commission zur Ermittlung der zweckmässigsten Sicherheitmassregeln gegen die Explosion schlagender Wetter in Bergwerken. Vienna, 1891.

5. A blown-out shot with coal-dust as tamping, or a charge of dynamite lying free, will ignite every kind of coal-dust. Most kinds of coal-dust were ignited with a charge of 100 gr. (3½ oz.), and all without exception were ignited with a charge of 300 gr. (10½ oz.).

6. A coal-dust which otherwise is not dangerous and takes fire with difficulty, may give rise to a disastrous explosion if there is a little fire-damp present.

The question continuing to be a very debatable one, Mr. Henry Hall was appointed by the Home Secretary, in 1890, to carry on a further series of experiments.* The result of these experiments being still non-conclusive, a Royal Commission was appointed in 1891, to inquire into the effect of coal-dust in originating or extending explosions in mines, whether by itself or in conjunction with fire-damp. This inquiry is not yet completed, but a preliminary report † has been issued giving the evidence taken up to date.

Sir F. A. Abel ‡ considers that, under extremely favourable conditions as regards the nature of dust, its physical condition and its composition, and the quantity of dust existing and suspended in the air at the time of the explosion, in the entire absence of fire-damp, coal-dust undoubtedly has the power of carrying on explosions almost to an indefinite extent in mines. He questions whether there is practically any limit, as, looking to the great commotion set up by the rush of gas produced as the explosion originates and as it progresses, the motion of the air is such that particles of coal-dust must be whirled up into it, and must continue to produce a mixture of sufficient intimacy and sufficiently highly charged with inflammable particles to develop afresh the conditions which existed originally when the explosion was started, and in that way the explosion may be considered to be a continuous one.

Mr. A. H. Stokes§ considers that the Prussian experiments proved that coal-dust, without a trace of gas, in a pure atmosphere, is not dangerous. Coal-dust in mines promotes, extends, and aggravates explosions due to fire-damp, by reason of the rapid inflammability of its finely divided particles. The sensitiveness to ignition of coal-dust and air, appears to be in proportion to the intensity of heat at the point of ignition, and the size and impact of the initial flame has a very important influence in controlling the propagation of flame. The condition necessary to ignite a mixture of coal-dust and air appears to depend on the temperature, volume, and the way in which the initial flame strikes the current; also that each atom of dust be surrounded by air so that it can get oxygen instantly, and that each atom be near enough to its neighbour to be able to communicate flame. He has not been able to find any record of an explosion in a dry and dusty mine in which gas had never been found. In most experimental cases where coal-dust was fired, the atmosphere was thickly charged with coal-dust—in fact, so thick that no living being could exist in it; and this was a state of affairs which could scarcely be found in any mine unless as the result of a serious explosion of fire-damp, nor one that a blown-out shot could create and fire with its own flame unless it were pointed directly into, and in close proximity to, an accumulation of dust. A mixture of air and fire-damp which cannot be detected by a safety-lamp, and which may be harmless in the absence of dust, may, if dust be present in sufficient quantities, become an inflammable mixture, and be the means of carrying flame as far as such mixture extends. The current of ventilation in a dry and dusty mine may be charged with such a low percentage of fire-damp that the most careful observer would fail to detect the blue cap indicative of fire-damp in the ordinary safety-lamp, yet it might be so charged with fire-damp that any unusual circumstances, such as a heavily charged blown-out shot or other violent concussion, might raise a cloud of dust and render the current at once an inflammable mixture. A comparatively small explosion in a dry and dusty mine giving off fire-damp, may be developed link by link into a most extensive disaster. The most dusty atmosphere of a mine, in its ordinary working condition, could not be ignited by the direct action of any blown-out shot. If the current of air be free from fire-damp, in no mine in its normal state, and the ventilation free from fire-damp, would an ordinary blown-out shot raise sufficient dust to make the ventilative current an inflammable mixture such as would ignite from the same shot, flame and create what might be termed an explosion, unless such a shot be fired directly into a bed or considerable accumulation of coal-dust.

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* Colliery Guardian, 1890, lx. 875.

† Blue-Book: *First Report of the Royal Commission on Explosions from Coal-dust in Mines*, July 1891.

‡ *Ibid.* p. 82.

§ *Ibid.* p. 103 and 104.

Action of Moisture.—It may now be regarded as established that small amounts of moisture are sufficient to prevent the possibility of coal-dust being ignited, and at many colleries the main roads are regularly watered. In order to be efficient the water should be applied in such quantities as will simply damp the dust and prevent clouds of it being raised by any means. If the floor be properly watered it is sufficient to prevent any deposit of dust on the sides or the roof. As a large quantity of dust is formed in the tubs during the progress of hauling them along the roads, a quantity of water is often thrown over the contents of each tub immediately before it leaves the working face.

Attempts have been made to render dust harmless by applying along the roadways some deliquescent body such as salt, but although the result in some cases has been satisfactory,* yet the method has not received many applications, the use of water being superior.

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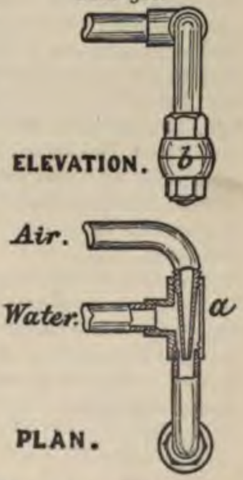
* N. E. I. xxxi. 145.

In some cases ordinary tubs are provided with a perforated pipe at the back, and the water applied in the same way as in streets of towns. If such a watering appliance is to be used, a good arrangement is that suggested by Messrs. Archer & Robson.* A circular brush is affixed to the rear of a tub, and is suitably connected by bevel gearing to the axle of the tub, so that when this moves along the brush is rotated. The spindle of the brush is hollow, and water is passed along it and through holes on the rim of the boss, and is thrown by centrifugal force from the tips of the bristle brush in the form of fine rain or spray.

Many collieries in South Wales are fitted with watering appliances, and the methods used have been described by Mr. A. Hood.† At Llwynypia Colliery, water-pipes are carried along the roads, and a fine jet allowed to issue at intervals, the spray being carried along by the air-current. Round outlet holes can be used when a deflecting plate is placed at a small inclination to the jet to drive it into spray. Flat jets, however, give a better spray, but round ones are less likely to be choked up with dirt. In some cases, even with the finest spray, the action of the water causes the roads to heave to a considerable extent, but at Ynishir Colliery, where two miles of piping are laid with outlet pipes at intervals of from 40 to 60 yards, little difficulty has been experienced from heaving. Of course this objection depends entirely on the nature of the roof and floor. The best procedure is to load up and remove the dust as much as possible before watering, as not so much water is necessary, and mud is not formed. Watering certainly makes the conditions more pleasant. At Pochin Colliery the intake air had been warmed and a jet of steam injected into it with satisfactory results. The warming of the intake air-current is, however, objectionable.

Mr. H. W. Martin has described the method in use at Dowlais, where a very elaborate system is applied.‡ Two mains are laid, one for water, and the other for compressed air. Out of these at intervals small branch pipes of half-inch internal diameter are carried to the roof, and then across, when they join together by a conical nozzle (*a*, Fig. 381) in the interior of an ordinary **T** couple. The water is forced out by the air through

Fig. 381.



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* N. E. I. xxxvi. 99. † South Wales Inst., xiv. 357 ‡ *Ibid* xv. 267.

an adjustable spray producer, *b*. The aperture in this is made adjustable, so that in the event of its being clogged by any sediment it can be "flushed" for an instant. The adjustment is made by a nut and screw. A regulating tap is placed in both the air and water branches, and to prevent entry of water into the air-pipe, and *vice versâ*, a small ball-valve on a leather seating is introduced into each pipe. The spray producer hangs vertically from the roof. An exceedingly fine spray is obtained, which is carried along with the air, and effectually damps the finest dust lurking behind timbers. It also cools the air-current, the experience at Harris Navigation Colliery being that the temperature of the intake has been reduced 4 to 5 degrees. The pressure of water should exceed that of the air, but it is only necessary that it should be a few pounds above. The spray producer is made of brass, and is globular in form. It can be opened in a second by unscrewing a nut at the bottom, when dirt is readily blown out.

The mixture of air and water not only produces a very fine spray, but it seems to act further owing to the intimate mixture, and hence the discharge jets can be placed at greater distances apart. There can, however, be little doubt that the velocity of the air-current influences in a great measure the distance to which the spray is carried.

Laws of Friction, &c.—Before describing how a ventilating current is produced and circulated through the workings, a short description should be given of the laws of friction and of the general rules relating to ventilation. The subject is such a complicated and extensive one that only the briefest summary is possible here. The finest series of papers in the English language are those by the late Mr. J. J. Atkinson,* which, although written so long ago, still remain the standard authority. To these, and others written at the same time by several of his contemporaries, the student is referred for detail of information and reasoning. The principal points dealt with, and brought out by the above series of papers, have been summarised and elucidated by Mr. W. Fairley.†

Currents of air, either on the surface or in a mine, are produced by a difference of pressure, and would flow at a great speed if no resistance were encountered. If v = the velocity in ft. per second, g = gravity, or 32.2, and h = the height from which a body must fall in order to generate this velocity, such height being the motive column,

$$v = \sqrt{2gh}. \quad . \quad . \quad . \quad . \quad (1)$$

The water gauge, which is the measurement of the pressure required to generate this velocity at which the air travels, *if resistance were absent*, would be a small one, and may be determined by the formula—

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* See list at end of chapter.

† *The Theory and Practice of Ventilating Coal Mines.*

$$\text{W.G.} = \frac{w \times h}{5.196} \quad . \quad . \quad . \quad . \quad (2)$$

where w = the weight of a cubic ft. of air at the temperature of the upcast, and h = the motive power.

Now

$$w = \frac{1.3253 \times \text{height of barometer (H)}}{459 + \text{temperature } (t)} \quad . \quad . \quad (3)$$

and

$$h = \frac{v^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\therefore \text{W.G. (in inches)} = \frac{\frac{1.3253 \times \text{H}}{459 + t} \times \frac{v^2}{2g}}{5.196} \quad . \quad . \quad (5)$$

From this formula it will be found, that if the air has a final velocity of, say, 50 ft. a second, the theoretical water gauge required to produce it is only 0.6 inch. Fifty feet per second is a velocity scarcely attained in mines, and it is equally rare that the water gauge only shows 0.6 inch. The difference between the water gauge due to velocity, and the actual water gauge of any mine, is the measurement of the friction which the air meets with in passing through the air-ways.

The three main laws which govern the friction of gases flowing through pipes are as follows:

(1) The frictional resistance varies directly as the rubbing surface; this rubbing surface is found by multiplying the length of the gallery by its perimeter, or, in other words, its circumference.

(2) The pressure required to overcome the friction varies inversely as the area, if the rubbing surface and velocity remain the same—that is to say, if two air-ways be taken, one of which is double the area of the other, only half the pressure has to be applied to each sq. ft. of the large one as would have to be applied to the small one, to overcome the same amount of friction in the two ways, provided the velocity of the air and the extent of rubbing surface were the same in each.

(3) The frictional resistance varies directly as the square of the velocity; consequently, if the velocity be doubled, the resistance increases four times. The explanation of this law is a simple one, if it be remembered that if the velocity be doubled, double the quantity of air passes through the air-way in a given time, and meets every resistance with double velocity.

From these laws the following formula is deduced:

$$pa = ksv^2 \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where p = the pressure in lbs. per sq. ft., a = the area of the air-way in sq. ft., s = the area in sq. ft. of rubbing surface, v = the velocity of air in feet per minute, and k is a constant called a co-efficient of friction, and is equal to the ventilating pressure required to overcome the resistance that a unit of air with unit velocity would meet with in circulating round a mine of unit area and having unit rubbing surface. The value of this co-efficient has never been satisfactorily determined for the irregular passages of mines. Although it is generally admitted that Mr. Atkinson's figures are not strictly correct, yet they are freely adopted. He states that it seems probable that for every foot of rubbing surface, and for a velocity in the air of 1000 ft. a minute, the friction is equal to 0·26881 ft. of air column of the same density as the flowing air, which is equal to a pressure, with air at 32° F., of 0·0217 lb. per sq. ft. of area of section.

The difference between pressure and power must be clearly understood; pressure is the force per sq. ft. producing the ventilation, and power is the quantity passing multiplied by the pressure. The quantity is found by multiplying the area by the velocity.

By transposing and substituting values of the different symbols in (6) nearly every formula can be deduced to work out the problems met with in ventilating mines. Several of the more prominent results obtained may be summarised as follows:—

(1) The quantity of air circulating in a mine is according to the square root of the pressure.

(2) In air-ways of the same sectional area, but which only vary in length, the volume and velocity of air currents are inversely proportionate to the square root of the lengths.

(3) The quantity of air passing in air-ways of different areas, other things being equal, is according to the square root of the area multiplied by the area.

(4) The resistance varies directly as the length.

(5) The pressure required to propel air through passages is inversely proportional to the area, other conditions remaining the same.

(6) If any two machines are employed to ventilate a mine, each of which when working separately will produce certain quantities which may be denoted by a and b, the quantity of air that will pass when the two are working together will be $\sqrt{a^2 + b^2}$.

(7) The quantity of air passing is according to the cube root of the power applied.*

(8) Since the quantity of air circulating varies as the cube root of the power employed, and as the number of revolutions of a fan also varies as the cube root of the power employed, it follows that the quantity of air circulating depends directly on the speed of the fan.

PRODUCTION OF AIR CURRENTS.—The problem of producing sufficient air, and of so carrying it into every part of the mine that the noxious gases are effectually removed, is one of great importance. By the law in this and in many other countries, every mine has to be provided with two shafts, or outlets; one of these serves for the introduction of the fresh air, and is called the "down-cast"; the other, for the egress of the current after it has passed round the workings, and is called the "up-cast."

Natural Ventilation.—No matter what the respective sizes of the two shafts may be, provided that they are connected by a passage and that the density of the air in the two columns is equal, no current is produced. If, however, the densities are different, the pressure of the one column of air will overbalance that of the other. The equilibrium in the two shafts is destroyed by the natural heat of the strata altering the density of the air. As a descent is made towards the centre of the earth, a proportionate rise of temperature is found—that is, after a certain limit is passed. This limit is found at a depth of about 50 ft., where the temperature of the rocks is on an average 50½° F., this temperature remaining constant all the year round. From the mean of numerous observations, it may be taken that the underground temperature increases 1° for every 60 ft. of depth below the invariable stratum. Therefore, the deeper the mine, the greater the difference of temperature of the air in the two shafts, consequently, the greater the ventilation.

From this cause ventilation is produced without any artificial assistance, and is called natural ventilation. It is, however, so inconstant as to be wholly unreliable, depending to a considerable extent on the temperature of the outside air, and the difference in the levels of the tops of the two shafts. In winter, the current may flow one way, and in summer the other. For such reasons natural ventilation is never to be relied upon, although it does in many cases materially assist the other means which are used to produce the air current.

Furnace Ventilation.—The oldest means of producing ventilation was to artificially alter the density of one of the columns of air by heating it. At first, this was done by merely hanging fire-lamps in the up-cast shaft, to be soon superseded by placing a furnace at the bottom, as by the latter means the greatest effect is obtained. Furnaces may be constructed on two main principles (a), either an open fire-place with all the air passing over the fire; or (b) contracting the area above the fire, and forcing the greater part of the current through the bars. Neither of these methods, separately, gives the best result. In the former, where a strong current is passed over the fire, its cooling action is so great that the combustion is feeble and a high temperature is not attained; while in the latter, if all the air passes through the bars, not only is carbonic oxide formed in large quantities, but the resistance or drag of the mine is much increased. A combination of the two gives the best results, and is almost invariably employed.

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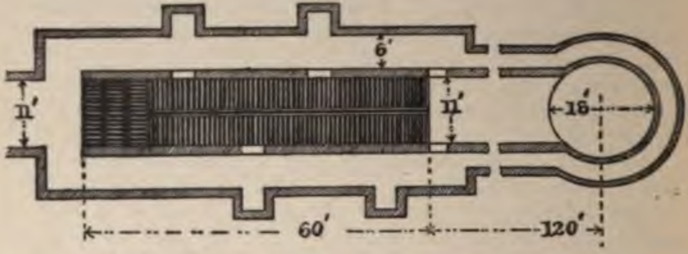
* A most interesting paper has been contributed to the Federated Institution of Mining Engineers (vol. ii. page 483) by Mr. W. Cochrane on a Duplex Arrangement of Ventilators, the results obtained agreeing remarkably well with the theoretical deductions given in (6) and (7).

No better illustration of a well constructed and efficient furnace can be given than that at Eppleton Colliery (Fig. 382). The length of the grate is 60 ft., and its breadth 11 ft.; the end of the fire bars are 120 ft. away from the shaft. An air passage and firing-hole is provided on each side of the furnace, and also an air passage along each side of the drift going to the shaft. This drift rises 1 in 2, and is lined throughout with fire bricks. With this large grate area, all the air passing over the fire is thoroughly heated, and, in addition, doors are provided at the front, so that the quantity forced through the bars can be regulated. Doors on furnaces are, to a certain extent, necessary, especially on re-starting after cleaning. The current, which is then small, can be forced through the fire, and as it increases, owing to the temperature getting high, the doors are gradually opened, and more air allowed to pass over the fire. The advantage of the side passages is, that not only may firing be entirely done at the side, but the risk of setting the adjoining strata on fire is reduced. A good casing of sand is placed all round these arches as an additional precaution.

FIG. 382.



At Eppleton Colliery, twenty-four tons of coal are burnt in the twenty-four hours. During two shifts a number of boilers are at work underground, so that the furnace does not produce all the air circulated. While these boilers are at work one man per shift is employed for firing, but at night two men are necessary; this means four men per twenty-four hours. The quantity of air circulated is 303,000 cubic ft. per minute, with 2 in. of W.G., but only 120,000 cubic ft. passes over the furnace.

In fiery mines it would not be safe to pass the return air-current over a furnace, and it has to be fed with fresh air. As the temperature at the bottom of the up-cast shaft is sufficient to ignite gas, the return air-current has furthermore to be brought through a passage called a "dumb-drift" into the shaft at some point above the furnace where the temperature has fallen below the igniting point. Neither feeding the furnace with fresh air nor carrying the return air-current through a dumb-drift increases the efficiency of furnace ventilation, but, on the contrary, diminishes it, as not only is the temperature of the air-current reduced, but a shorter column of air is heated.

The amount of ventilation produced by a furnace varies as the square root of the difference of temperature in the two shafts—that is to say, if the mean temperature of the down-cast be 50° F. and the up-cast 75° F., if the temperature of the up-cast be increased to 150° the ventilation will be doubled, as the difference in the first instance was 25° and in the second 100°; therefore,

$$\frac{\sqrt{100}}{\sqrt{25}} = 2.$$

The objections to furnaces are the danger of introducing fire into mines yielding fire-damp, the risk of setting adjacent coal on fire, the corrosive effect on all shaft-fittings and tubbing, and to the fact that no more than a certain quantity of air can be got out of a given furnace, no matter how much coal is used.

Furnaces are most objectionable where tubbing is employed, as the wood sheeting between the segments is continually being burnt out. Lining with brick-work offers little protection, as when the fires are damped down (for repairs to furnace or drift) the tubbing contracts so much that a large escape of water takes place, which, in some instances, so cools the shaft that the air-current is reversed. Where tubbing is employed, it is practically impossible to stop firing. In some cases in the north of England, which is the home of furnace ventilation, a second furnace is often built, and when the first is slacked for repairs the second one is started.

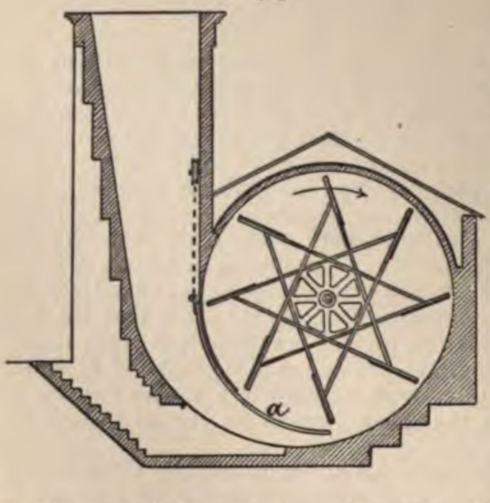
Steam Jet.—In the early part of the century, Sir Goldsworthy Gurney proposed that furnace ventilation should be superseded by the use of a steam jet. Steam at high pressure was to be carried in pipes down the shaft, and allowed to escape at the bottom through a series of jets arranged gridiron-fashion across the pit. As it was soon found that this method was neither so economical, nor so capable of producing large volumes of air, as a furnace, its use was abandoned, and except in cases of emergency it is never employed.

Mechanical Ventilators.—From the earliest times attempts were made to produce currents of air by mechanical means. The first forms consisted of a species of pump, which, in its improved form, represents the modern displacement machine. Other attempts were made to circulate air by the rotation of fans, which was not attended with much success until about thirty years ago.

The comparative efficiencies of displacement machines and centrifugal ventilators have been exhaustively dealt with by Mr. W. Cochrane.* The chief disadvantages of the former are the heavy and cumbrous machine which has to be employed to produce large quantities of air, and the defect that, if there are sources of leakage in the apparatus, the volume of external air thus let in would *increase* as the depression increases, and, therefore, the air drawn from the mine will *diminish*. The re-entry of air must always be considerable, as a shutter is employed, which is neither rigid nor even, in contact with the casing.

The theoretical objections have been fully sustained in practice, and at the present time displacement machines have been entirely superseded by fans, of which numerous and varied types exist. It would be quite impossible to describe the steps which have led up to the latest designs, or even the whole of these designs. Reference can only be made to those largely in use, and which give good results.

FIG. 383.



Guibal.—This fan usually consists of eight or ten rectangular vanes, which are not, however, arranged radially, but are set backwards, as will be seen from Fig. 383. Each vane is secured to a pair of bars and angle-irons, which, in their turn, are bolted to cast-iron bosses, keyed on the main shaft. As these bars are carried past the bosses and interlaced, a very firm, simple, and inexpensive structure is obtained. The fan is enclosed in a casing, giving about ½ in. to 1 in. clearance on each side. Over the fan an arch is provided, giving about 2 in. clearance to the vanes, such arch being continued round as an invert, but towards the bottom the clearance is increased, and gradually expands until it ends in the sloping side of a chimney.

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* N. E. I. xxvi. 161.

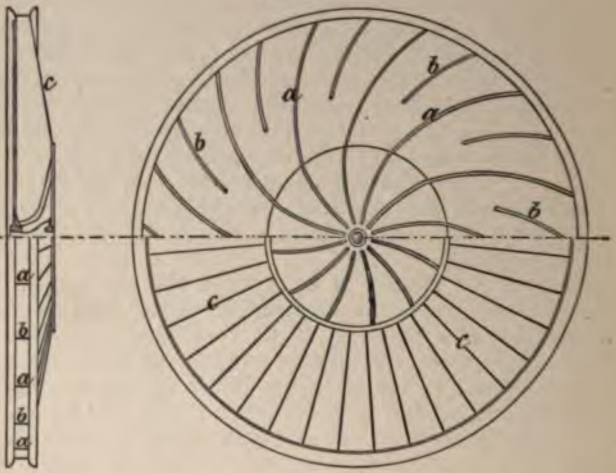
In its original form this fan differed from all others in one point: it was provided with a sliding shutter, *a*, which is really a continuation of the circle of the top arch of the casing. This shutter allowed the area of the discharge opening to be regulated and fixed at such an amount that the best results could be obtained. In many fans only one inlet orifice was left in the casing. On the other side a blank wall was provided, through which the shaft of the fan passed, and was connected to an engine. For machines of small capacity such arrangement acted very well, but in the larger fans it was not only found that the ventilator did not get sufficient air, but that all this air, entering on one side, and doing so diagonally, threw a severe thrust on the shaft and its bearings. For such reasons it was found preferable to give such fans a double inlet, that is to say, leave a circular orifice through the casing on both sides.

The use of the shutter is to regulate the outlet to suit the special requirements of the mine, and its proper position can only be determined by experiment, as no theoretical calculations will determine the quantity of air that any fan will produce from any particular mine. If the discharge orifice be too large, air will re-enter the fan, while if it be too small, the air will not get away fast enough. The use of the expanding chimney is to reduce the velocity of the air as it leaves the fan. When the air leaves the vanes, it is travelling at a very high velocity, but as it passes up the chimney, whose area increases as it expands, it gradually travels slower and slower, until at the top it is discharged quietly into the atmosphere.

From its simplicity, freedom from repairs, and high efficiency, the Guibal fan has been in marked favour ever since its introduction in 1862, and probably more of its type have been erected than of all the other fans put together. The objection to the Guibal is its very large size, the expensive foundations required, and that it cannot be run above a certain velocity with safety. The latter difficulty has been removed by Messrs. Walker Bros. shutter, which is described a little further on, but even with this the tendency at the present time is to put down some of the smaller type of fans which run at very much higher velocities.

Waddle.—This is of an entirely different type to the Guibal, being what is known as an open running fan—that is to say, it is not enclosed in a casing, and air is discharged all the way round the circumference instead of only at one point. As constructed until recently, it consisted of an arrangement of long and short curved blades arranged alternately between two iron discs; one of these discs is provided with a central opening through which the air passes into the fan, and is inclined towards the other disc at such an amount that the products of the angular velocity, multiplied by the sectional area at any point, are constant throughout the fan. Mr. Walton Brown* has described several modifications, which have been recently introduced. In the old type the air was discharged into the atmosphere at a somewhat high velocity, but in the new fan its velocity is considerably reduced by the addition of a trumpet-shaped outlet which extends beyond the external ends of the blades. Fig. 384 shows the fan as constructed at the present time; *a* and *b* are the curved blades, the former running down to the centre. The area of this outlet is more than double the area described by the external tips of the blades, consequently the velocity of the air is gradually reduced as it passes through this divergent outlet, and as the resistance varies with the square of the velocity, less power is required to discharge the air, and therefore less power is required to drive the fan, the result of which is to increase its efficiency. In addition, the blades are brought in towards the centre, and the air strikes all parts of them equally, but to give the maximum area for the

FIG. 384.



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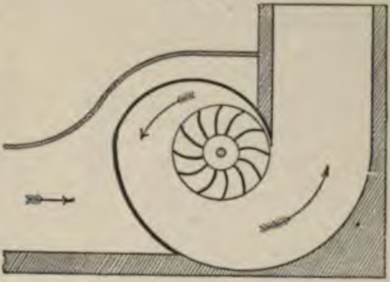
* Fed. Inst. ii. 173.

entrance of the air, the long blades, *a*, are reduced in width as they near the centre. The disadvantage of open-running fans is their liability to be affected by high winds.

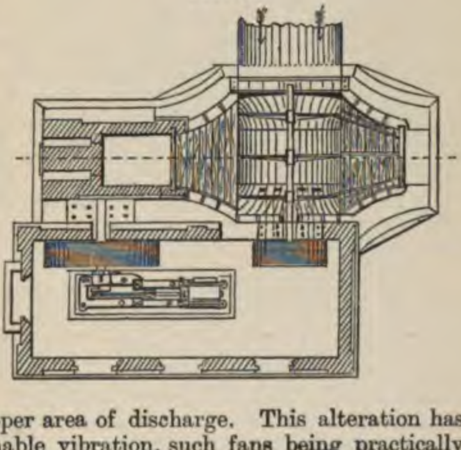
Schiele.—This is an enclosed fan, but is not placed centrally within the casing (Fig. 385). The moving part is small in diameter, and the blades of the fan taper from the tip widening towards the centre. The air enters at each side in equal proportions, and the vanes revolve between a casing of such form that its sides follow the taper of the blades, while the circumference is arranged as a gradually increasing volute chamber surrounding the periphery of the blades, culminating in the exit, which forms the widest part of the air chamber.

FIG. 385.



Cockson.—The objections to the Guibal, as before mentioned, are its great weight, size, and the vibration resulting from its unbalanced nature. To remedy the latter defect, Mr. Cockson has modified the ordinary construction. The close-fitting casing, expanding chimney, and adjustable shutter are retained, but the blades taper from the centre to the circumference in such proportion that an equal area of air passage is obtained throughout the fan (Fig. 386). The expanding chimney is not so wide in one direction owing to the blades tapering, and its width is, therefore, increased in the other direction so as to obtain the proper area of discharge. This alteration has removed the objectionable vibration, such fans being practically noiseless, and as they are more balanced, can be run at a higher speed, thereby allowing a smaller one to be used.

FIG. 386.



Capell.—This fan (Fig. 387), is a departure from all others in its arrangement and construction. All sizes above eight feet diameter are constructed with a double inlet. The fan is divided both vertically and horizontally, into chambers. The vertical division consists of a stiff steel diaphragm, *a*, which entirely separates the air received on one side from that of the other. The horizontal division consists of a cylinder, *b*, having a series of port-holes through it, and usually six blades, *c*, projecting inwards, curved with the convex side in the direction of rotation. The air first enters into this cylindrical chamber, and is discharged through the port-holes, *d*, at a very high velocity against the inner and concave side of the outer wings. It is claimed that to an extent the *vis viva* in the air is given up to the outer wings and actually assists in driving the fan. The velocity of the air is also reduced, as the size of the external chamber is greater than the internal one, and when it leaves the tips of the blades a further reduction takes place as the air is discharged into a spiral volute chamber, and finally passes, by means of an expanding chimney, into the open air.

FIG. 387.

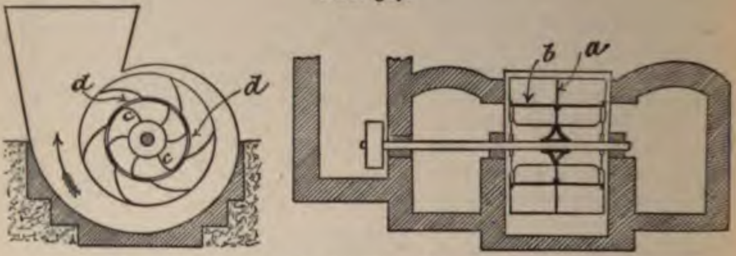
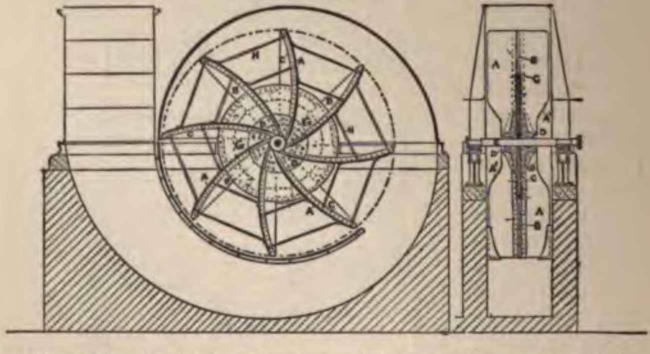


FIG. 388.



Walker.—This is one of the more recently designed fans, and is more or less a combination of several types. It has Guibal blades, chimney, and shutter, but it is placed eccentrically in the casing like a Schiele. Its construction is of the strongest type, and it is claimed by the makers to be indestructible. It is built up somewhat as follows: In the centre is a mild steel disc, G (Fig. 388), which does not, however, reach the circumference as in the Capell. On each side of this are angle-irons, C, to which the vanes, A, eight or ten in number, are attached. Rivets pass through the two angle-irons and disc, and through each angle-iron and blade. The disc is supported between two iron bosses, D, turned where they come in contact with the disc plate, and secured thereto by turned bolts driven into rimered holes. The bosses are bored out and secured to the fan shaft by keys. The blades in the larger fans are also braced together by struts, H, and strengthened by a gusset-stay, B, and instead of being full width from the top to the boss, they are cut away, as shown at A, in the cross section, and, if necessary, removable pieces are attached by bolts, to partially fill up the opening. By doing so, it is claimed that the minimum amount of central obstruction with the largest amount of fan power could be secured in each case.

The two fans last described seem to be the ones most in favour at the present time; both of them have high efficiency and both are cheap. Neither, however, have been in use long enough to determine whether their wearing capacity is equal to that of the larger slow running fans, which have been so well tried and proved in the past.

Walker's Shutter.—The object of this invention is to reduce the objectionable noise and vibration caused by rotary fans. In the ordinary Guibal, the edge of the shutter forms a horizontal line parallel with the shaft of the fan, and faces the blades. A little consideration will show that during the revolution, as each blade nears the discharge orifice, it has on it a large pressure, but as soon as the tip of the blade and bottom of the shutter coincide the delivery of air is abruptly terminated, the fan enters the fan casing, the load is removed, and a rebound necessarily takes place. The jerk thus caused, is transmitted to the fan shaft, and as each arm acts in a similar manner, the result is, that the whole structure is in a constant state of vibration, and injury to it must necessarily follow.

Messrs. Walker replace the horizontal edge of the shutter with an inverted V, thus, Λ. Each blade commences to discharge at the broad part of the Λ, and as it proceeds on its journey meets with a gradually decreasing area of discharge orifice, until at the top of the Λ all egress of air is stopped. As a result, the pressure of air is gradually taken off each vane. The length of the Λ is somewhat greater than the distance between two blades, so that the following vane may be opposite the commencement of the shutter before the blade next in advance has entirely left it. Without doubt, this is one of the greatest improvements which has been added to enclosed fans of late years.

Driving by Straps and Ropes.—High speed fans, except in rare instances, are not driven direct by engines, but through belts, or better still, by a number of ropes working in grooved pulleys. With a steady running fan-engine high degrees of expansion can be used, as the work is uniform, but such procedure causes a certain amount of shock to the fan, as the piston receives full pressure of steam at beginning of stroke. Then steam is cut off, and the rest of the revolution is due to the momentum obtained and the expansion of steam already in the cylinder. The fan is thus practically driven by a series of kicks.

Belts or ropes take up this shock. Ropes, although more expensive than belts in first cost, are, perhaps, the best in the long run. If a belt breaks, all the machinery is stopped, but all the ropes will never break at the same time. The only mistake that can be made is to put too great a strain on each rope, by which wear becomes very rapid. These ropes are constructed of hemp, and to obtain sufficient grip are generally made to run in grooves, whose sides are inclined towards each other at an angle of 45°. The ordinary method of application is to have each rope in separate grooves. They are pulled very taut at first, but get less tight as the rope lengthens. Another method is to wind a single rope round the two pulleys as many times as required for the necessary horse-power, and to put on a tension pulley to get the required grip and to take up slack.

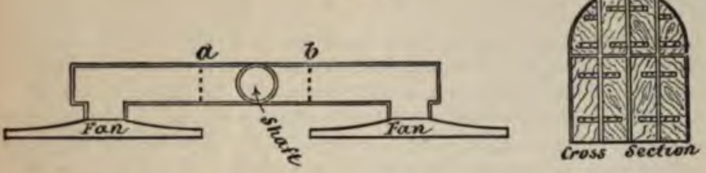
The wear of a rope is due to two causes: internally, by the movement of the fibres on each other due to the bending on the pulleys, and, externally, through the wedging and slipping in the grooves of the pulley, both of which may be said to be directly proportional to the speed. Rope drives have only been employed for about the past twelve years, and have not been in use sufficient time to determine their wearing capacity; it, however, appears to be unlimited.

Arrangement of Engines, &c.—To minimise the result of a breakdown in the engine, it is usual to apply two to a fan, each working alternately for certain lengths of time, generally about three months at a stretch.

This arrangement only provides relief in case of accident to the engine, and if the fan breaks down everything is stopped. Of late years it has become common to duplicate the whole of the ventilating machinery, and work each fan alternately. A very good arrangement for two ventilators, as applied at Celynen Colliery, South Wales, is shown in Fig. 389. Two Waddle fans, each 45 ft. diameter, are situated as illustrated. The air-drifts are 16 ft. wide by 21 ft. high, and in each one, at points *a* and *b*, are eight wooden doors, working in iron frames (see cross section). These doors open *towards* the fans.

To change fans, the one that has been standing is started, and speed gradually got up to about 40 revolutions. The other fan is slowed down to 50 revolutions, while the speed of the second fan is increased; immediately the revolutions of the second fan exceed those of the first, the air doors in its drift open, and at the same time, those going to the first machine shut. The first fan is then stopped, and the speed of the second one increased to the ordinary amount.

FIG. 389.



Determination of the Useful Effect.—The amount of useful effect produced by a fan is found by carefully determining the quantity of air put into circulation by it, and by measuring the water gauge. Each inch of water gauge is equal to a pressure of 5.2 lbs. per sq. ft. The horse-power in the air

$$= \frac{q \times \text{W.G.} \times 5.2}{33,000}$$

where q = the quantity of air in cubic ft. per minute and W.G. = water gauge in inches.

While the air measurements are being taken, the speed of the engine is carefully noted, and indicator diagrams taken, from which the mean steam pressure in the cylinder is determined. The H. P. of the engine

$$= \frac{p \times d^2 \times .7854 \times 2 \times \text{S} \times \text{R}}{33,000}$$

where p = the average steam pressure, d = the diameter of the cylinder, S = the length of the stroke in feet, and R = the number of revolutions per minute. The ratio between the horse-power in the air and the horse-power exerted by the engine gives the useful effect of the fan.

It must be admitted that, in comparing fans, it is scarcely fair to do so, without deducting the power required to drive the engine when it is not connected to the fan. The higher type of engine in perfect condition necessarily absorbs less power to drive it than a badly designed machine in an indifferent condition; it may, therefore, happen that a good fan driven by a bad engine will not show such a high efficiency as a less perfect fan driven by a good engine.

Efficiency of Fans.—No matter whether the fan is a large one, running slowly, or small one, travelling at high velocity, the work done depends on the speed of the periphery, or tangential velocity. The theoretical depression which a perfect fan would produce is determined by the formula—

$$H=\frac{u^2}{g}$$

where H is expressed in feet of air column required to overcome the resistance of the mine, and u = tangential velocity in feet per second. This depression is never realised in practice, owing to several causes, the chief of which is the resistance of the machine itself to the passage of the air through it. The theory of ventilators now generally accepted is that of Mr. Murgue,[*] the third part of which has been translated into English by Mr. A. L. Steavenson,[†] to which the student is referred for the reasoning by which the following formulæ are deduced.

Mr. Murgue assimilates every mine to an orifice in a thin plate, which he calls the "*equivalent orifice*," that is to say, all mines requiring a certain water gauge for the production of a certain volume of air are exactly equivalent to an orifice in a thin plate which requires the same water gauge to pass the same volume. By this means all existing mines can be compared by the sizes of their orifices.

The equivalent orifice depends upon the well-known laws relating to the flow of fluids, being chiefly affected by what is known as the *vena contracta*, or the quantity which passes through an orifice in a thin plate is 0.65 that of the quantity due to the area of the full orifice. If it is assumed that the normal densities of air and water are respectively 1.2 and 1000 and expressing V, the volume, in thousands of cubic feet per minute and h in inches of water gauge, the equivalent orifice a will be found from the formula—

$$a=0.403\,\frac{V}{\sqrt{h}}$$

The second point of Mr. Murgue is that the ventilator even while exhausting the air from the mine, forms at the same time an obstacle to the passage of the air, causing a sensible loss of duty. This he calls the "*orifice of passage.*"

In order to compare two machines, they are regulated to the same speed of periphery, or their results may be easily reduced to equal speeds, since the volumes vary as the revolutions, and the depressions as the square of the speeds.

The mine is altered to, say, five different conditions, first, by obstructing the passages; then in a normal state; and afterwards by opening some of the doors.

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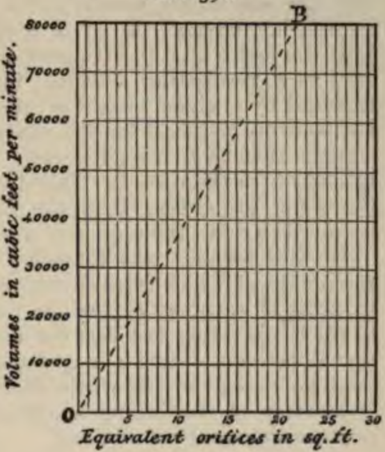
[*] Soc. Ind. Min. (2e Série), 1st part, ii. 445; 2nd part, iv. 747; 3rd part, ix. 5.

[†] *The Theory and Practice of Centrifugal Ventilating Machines.* London. 1883.

With the equivalent orifices of these five different mines, or conditions of mine, plotted as abscissæ, and the volumes as ordinates, a curve is obtained, which clearly shows the effectiveness of each fan, and is called its "*characteristic curve.*"

FIG. 390.



A perfect fan moving without friction and giving the theoretical water gauges, produces volumes of air proportional to its equivalent orifice, and its curve is represented by a straight line, O B, Fig. 390, commencing from the origin, because when the mine is closed the volume of air is necessarily *nil.* Owing to the resistances of the fan itself which vary with the volume produced, the straight line is never obtained in practice, but a curved one takes its place. The nearer this curved line approaches the straight one the more perfect is the fan.

In calculating the efficiency of fans the chief error which is likely to arise is neglecting the amount of natural ventilation, as, if this is large, it has to be passed through the fan, and in doing so little or no water gauge is produced.

Under favourable conditions, and with a machine designed for the work it has to perform, the efficiencies of the Guibal and improved Waddle fans may reach 65 to 70 per cent., while that of the Schiele fan is smaller. The efficiency of the Capell and Walker fans is probably higher than the above figure. Any fan dealing with the maximum quantity of air that it was designed to pass, gives better results than if the quantity of air put into circulation is either more or less than the amount for which it was designed.

It is very difficult to arrive at the relative merits of the different types of fans, as comparisons are apt to be misleading. In order to arrive at a trustworthy conclusion, the fans should be of equal capacities and be working under the same conditions. The latter condition can scarcely be fulfilled unless the fans are applied to the same mine. In order to determine the relative merits of the various types of fans, the North of England, the South Wales, and the Midland Institutes of Mining Engineers have appointed a Committee, but unfortunately their report is not yet issued (May 1893).

Comparison of Furnaces and Fans.—Mr. J. J. Atkinson appears to have been the only person to theoretically compare the relative efficiencies of furnace and mechanical ventilation.* After considering the varying circumstances of different mines and the conditions under which furnaces and fans produce a ventilating current, he gives a formula from which it appears that the depth at which furnace action becomes as economical in fuel as a ventilating machine, increases directly as the volume assumed by a given weight of air as due to the average upcast temperature required for the production of ventilation by furnace action—that is to say, inversely as the average density of the heated air in the upcast. This depth, of course, must decrease in the same proportion that the fuel per horse-power per hour, required to drive the engine of a ventilating machine increases.

By this formula the following table was calculated, showing the depths at which furnaces become equal to ventilating machines in point of economy of fuel, on the assumption that the fuel due to the temperature lost between the furnace and the point in the upcast column, where the average temperature prevails, is the same percentage of the whole fuel as that which arises from the application of ventilating machines, driven by engine power, to produce the same ventilation:

Consumption of Coal by Engine in lbs. per hour per horse-power expended.	AVERAGE TEMPERATURE OF UPCAST COLUMNS.		
	100° F.	150° F.	200° F.
	Depth in Yards.	Depth in Yards.	Depth in Yards.
8	958	1044	1130
10	766	834	904
12	638	696	752

A table is also given showing that the average loss in eleven cases of furnace action was 40 per cent. If therefore ventilating machines lose 40 and utilise 60 per cent. of the engine power, the depths that are necessary to render furnace ventilation as economical as such ventilating machines in the consumption of fuel are as stated above. It should, however, be noted that many engines at the present day do not consume 4 lbs. of coal per horse-power per hour, and hence the economy of fan ventilation is more than that shown by the table.

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* N. E. I. vi. 135.

Mr. C. Cockson, after giving a description of a fan at Dairy Pit, Wigan,* stated that the plant was erected to take the place of two underground furnaces, having a fire-bar area of 129 square feet on which 12 tons 17 cwt. of Arley mine mixture were burnt per 24 hours, producing, with the furnace very hard fired, 142,570 cubic feet of air per minute, the cost for wages being 19*s.* 3*d.* and for fuel £4 3*s.* 7*d.*, or a total cost of £5 2*s.* 10*d.* per 24 hours, which, multiplied by 365, will be £1876 per annum. The fan gave the same quantity of air as the furnaces when running at 52 revolutions per minute, burning 4 tons 2 cwt. of rough buzzard slack per 24 hours, and costing for wages, 10*s.* 6*d.*, and for fuel, 15*s.* 4*d.*; or a total per day of £1 5*s.* 10*d.*, which, multiplied by 365, gives a cost of £471 per annum, or a saving by the use of the fan on the two items of fuel and labour of £1405 per annum. Of course, from this an allowance has to be made for interest, depreciation, stores, &c.

Many similar instances could be quoted if it were necessary, but it is now generally admitted that mechanical ventilation is superior to furnace ventilation, as it is more under control, cheaper, more efficient, and capable of being easily varied in quantity whenever desired.

DISTRIBUTION OF THE AIR CURRENT.—Having described the means of producing the air current, and the laws which regulate its flow, its distribution underground should be readily understood. It has been mentioned that two paths are provided for the current, one for the fresh air to enter and the other for its return. The distribution into the workings is a far more difficult point than simply leading it along two roads. To reduce resistance and allow large volumes to be readily passed, it is necessary that the air-ways should have as large a section as possible. As the resistance varies with the square of the velocity, the only practicable way to pass large quantities is to reduce the velocity, which may be done by diminishing the rubbing surface, increasing the area of the air-way, or better still, by what is known as splitting, that is to say, dividing the current into several parts, and providing a separate air-way for each. Supposing one current of 100,000 cub. ft. exists in the mine, and passes down an air-way having an area of 100 sq. ft., its velocity would be 1000 ft. a minute. If this current be divided into five, each of which contains 20,000 cub. ft., the same total quantity will be passed through the mine, and if each of these currents be provided with an air-way 100 sq. ft. in area the velocity will be 200 ft. per minute, or only one-fifth of what it was before, consequently the resistance is reduced to one twenty-fifth part.

The enormous gain resulting from splitting the air is at once apparent, but it must be remarked that there is a limit to the number of splits that can be used at any mine. All the splits, however separate they may be kept in the workings, have to unite at the bottom of the upcast shaft, and pass through it; therefore, when the resistance of the shaft is equal to the sum of the resistance of the air-ways, the limit of advantageous splitting is reached.

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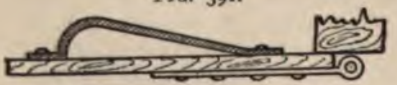
* Man. Geo. Soc. xvii. 231.

To obtain the best results from splitting the air-current it is necessary that every split should commence as near as possible to the shaft bottom, and have a separate in-take and return, and that the splits should approximately be of equal lengths, to avoid the necessity for regulating doors.

Stoppings.—When the two main roads are being driven, one for the in-take, and the other for the return, they are connected at intervals by cross-drivages, and those nearest the shaft are stopped up again immediately another one nearer the face is driven. These stoppings are usually built of dirt or rubbish, and a brick wall put on the side nearest the in-take current. Every care should be taken that this is air-tight, or a small quantity will escape through and pass away to the up-cast shaft without doing any good. The practice is sometimes followed of leaving a small hole through the stopping to ventilate the cross-road, but it is difficult to see how this can do any good, as the quantity of air which escapes through is so small, that it cannot effectively ventilate the road; while the total loss occasioned by a number of such outlets seriously reduces the quantity passing into the workings.

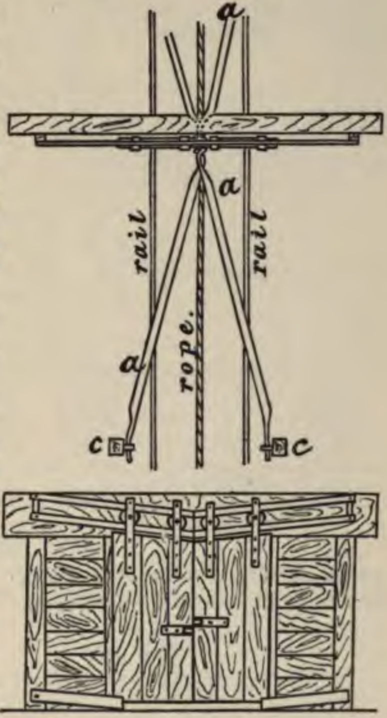
Doors.—Where tubs, men, or animals have to pass through these cross-roads, doors replace the stoppings previously referred to. Generally two and often three sets of doors are employed, the object of which is to prevent the possibility of all being open at the same time. The main doors which are of a permanent character, should be built in a masonry abutment, carefully made and fitted, and provided with a latch. If tubs travel through the road a guard should be fixed to each door to prevent the tub striking the woodwork; this usually consists of a curved strip of flat iron, bent as shown in plan by Fig. 391. Unless this precaution is taken, sooner or later the door will be damaged, and leakage of air follows.

FIG. 391.



It sometimes happens that doors have to be placed in roads where haulage is carried out by mechanical means, although such practice is by no means to be recommended. Either special boys have to be kept to open and shut these doors at the proper time, or, what is still better, a self-closing door, illustrated in plan and elevation (Figs. 392 and 393), which is adopted at Hetton Colliery, can be used. The door is in two divisions, hung by pulleys travelling on rails, these being arranged at such an inclination that the two halves run together by their own weight, and shut close. Hinged to the edge of each half where it meets the other, and about 2 ft. from the bottom of the door is a stout piece of angle steel, *a a*, about 8 ft. long, the outer end of which passes through an eye bolt fastened to a tree, *c*, this being placed as near the rails as will only just allow the tub to pass. When a set reaches the door, the first tub encounters the bars, *a*, presses them outwards, and in doing so opens the door, which closes again when the last tub has gone by. As this arrangement is similar on both sides of the door, it is opened equally easily whichever way the set is travelling, and the motion being gradual there is a complete absence of shock, so noticeable when the tubs strike against ordinary doors.

FIGS. 392 AND 393.

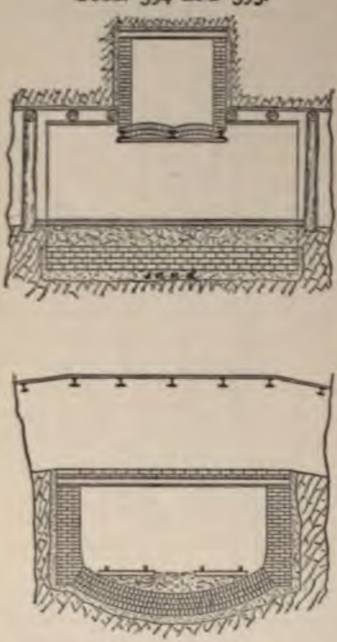


Regulating Doors.—If all the splits are of equal length and the air-ways of equal area, the same resistance is encountered by each, but as such condition scarcely ever exists, artificial resistance has to be added to regulate the quantity passing in each split to the desired amount. If it were not, the shortest splits would take the largest quantity. This regulation is effected by an opening in a door, such being covered by a sliding shutter, which can be set at any point to give the desired result.

Air Crossings.—In splitting air, one current has to pass over, or under, the other, but it must do so in a separate conduit. This is effected by what are known as air crossings. A temporary form is to build, where two roads cross each other, a brick wall on each side of the intake current, place two timber bearers on the top, and connect the two walls by planks laid across. The incoming current passes between the walls underneath the planks, while the return air passes over the walls and planks.

This construction results in great loss by leakage, especially if there is any movement in the ground. At Lye Cross pit, crossings are used as illustrated in Figs. 394 and 395. In the in-take road an invert of masonry and two side walls are built, girders put across from one to the other and bricked in between with small arches. The return airway is formed by carrying two walls up to the roof, this being also capped by girders which run at right angles to those previously mentioned. The construction is very solid, but is required on account of the movements in the strata, which, if not prevented, would result in serious leakage.

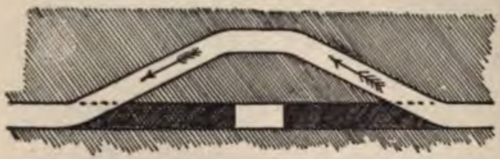
FIGS. 394 AND 395.



In fiery mines, should an explosion happen, all stoppings constructed in the ordinary way would be blown down, the two currents intermingled and ventilation entirely suspended. To provide against such contingency, it is often the practice to drive the return air-way some considerable distance above the intake (Fig. 396).

Loss in Circulation.—By the aid of stoppings, doors, and air crossings the currents are regulated and made to follow certain paths at will, in order that ventilation shall be carried into the workings and perform its mission. The greatest care must be taken to reduce leakage through cross roads, but in spite of all precautions only a portion of the air that passes through the down-cast shaft reaches the working face. It is difficult to believe how small this portion is, but the following example given by Mr. Henry Palmer* may be quoted, showing the great loss. A ventilating current was measured at several places during its passage from

FIG. 396.



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* Brit. Soc. Min. Stud. xi. 46.

the down-cast shaft to the workings. It is stated that the doors in the seam in question were well fitting and double, and that the stoppings were made as solid as possible, and well stowed. The first measurement was taken 140 yds. from the shaft, and the quantity found to be 16,650 cub. ft. per minute. At 805 yards from the shaft the quantity was 12,550 cub. ft.; about this point a split of 3140 cub. ft. passed away to ventilate an engine and travelling road. At 1470 yds. from the shaft the quantity was 7700 cub. ft., and immediately after this point a second split of 3510 cub. ft. passed away to ventilate another district. At the face of the workings, 2200 yds. from the shaft, the quantity was 1560 cub. ft.

It will, therefore, be seen that while 16,650 cub. ft. left the shaft, only 1560 cub. ft. reached the face. From the initial quantity, however, the two splits alluded to, must be deducted, viz., 3140 and 3510, making a total of 6650 cub. ft. Deducting this from 16,650, leaves 10,000 cub. ft. and a very simple calculation will show, that no less than 84.4 per cent. of the air current was lost in its passage from the shaft to the working face.

MEASUREMENT OF AIR CURRENTS.—In order to determine the quantity of air passing, the velocity has to be ascertained. This, multiplied by the area in sq. ft. at the point of observation, gives the quantity of cub. ft. of air. The velocity may be determined by several methods, only two of which need, however, be considered.

In the first, some light body, such as smoke, is employed, and the time it takes to travel a measured distance noted. Even when exercising the greatest care, the results obtained are not exact, although near approximations are given. If the road is of uniform area, some definite quantity, such as one cubic inch of gunpowder, should be always employed.

Anemometers.—At the present time, the invariable practice is to employ what are called anemometers for measuring the velocity of the air current. The common form is known as Biram's (Fig. 397), which consists of a series of vanes, *a*, placed obliquely to the axis like the sails of a windmill. An indicator, or counter, is placed in the centre. The axis of the vanes carries an endless screw, which gears into a wheel, to which a pointer is connected. Another form much used is Casartelli's, which is very similar to the Biram, but usually made with five dials, registering units, hundreds, thousands, &c., and, in addition, a small lever or stop is provided, by means of which the counting mechanism can be thrown in and out of gear.

With the two anemometers just described the velocity is measured by holding them in the air current for a certain length of time, and noting the number of revolutions. This means that two persons are required, as one man cannot hold a watch, anemometer, and lamp with two hands. Davis's self-timing anemometer dispenses with the use of a watch altogether, and registers at once the velocity in feet per second, and not the number of revolutions of the vanes. In taking observations the instrument (Fig. 398), is held out at arm's length for a short time until the vanes are travelling at full speed due to the air current, a small button, *a*, is pressed, and the pointer turns to the speed, and is kept there by a locking arrangement. Each instrument being graduated by experiment, no allowances have to be made. To return the pointer to zero, the small milled head *b* is screwed down until *a* is released, when as soon as *b* is unscrewed, the pointer turns to zero, and the instrument is ready to take another observation. Two graduated circles are provided, and a pointer, *c*, travelling in a small dial, informs the observer which one to read.

FIG. 397.

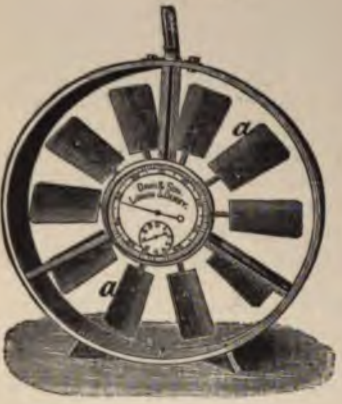
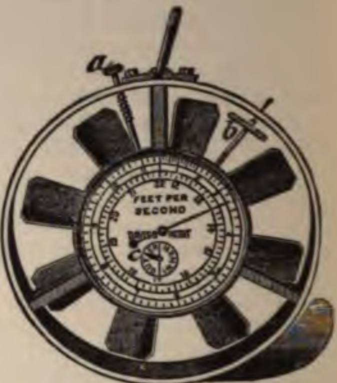


FIG. 398.



Messrs. Davis & Son have recently introduced a new form of anemometer for measuring currents of high velocity (over 20 ft. per second). It is called the "Capell-Davis," as the vanes are shaped like those of the Capell fan. It differs from anemometers on the Biram principle in having the vanes rigidly attached to a blank disc. As a result, the wind pressure bears equally on the whole surface, whereas in the old construction it might impinge on one vane more than another and distort one of the delicate arms.

Messrs. Atkinson & Daglish * conducted a series of experiments with anemometers, and determined that they all required correction, to bring the velocity they recorded to the true velocity at which the air is travelling. The true velocity may be determined by the formula,

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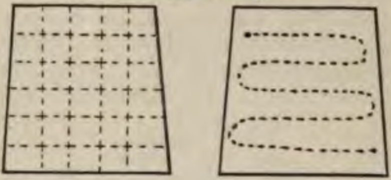
* N. E. I. x. 207.

$$v = aR \times b$$

where a is a constant proportional to the number of linear feet travelled by the air per revolution, R is the number of revolutions registered by the anemometer, and b the losses of velocity due to friction of machine, this loss being determined experimentally by a whirling machine.

Instead of this formula, the correction is usually made by adding numbers, which are supplied by the makers, and which vary for every instrument and for different velocities. Anemometers are necessarily of very light and fragile construction, and easily get out of order. It, therefore, becomes necessary if accuracy is desired, that they should be tested from time to time.

FIGS. 399 AND 400.



In order to obtain trustworthy results, the places of measurement must be of uniform section and preferably divided, by a series of horizontal and vertical strings, into a number of equal parts (Fig. 399), and the anemometer placed in each for a certain length of time. If a disengaging gear is applied to the instrument, it should be placed in the current, and allowed to attain the full velocity before throwing the mechanism into gear. For very accurate results the observations should be taken in each division. Mr. Murgue, however, states, that the ratio between the mean velocity and the velocity at any given point in the same section remains constant, whatever variations there are in the mean velocity. It is only necessary, therefore, to find the ratio between the mean velocity, and the velocity of air at any one convenient point, and in future merely measure the velocity at that point.

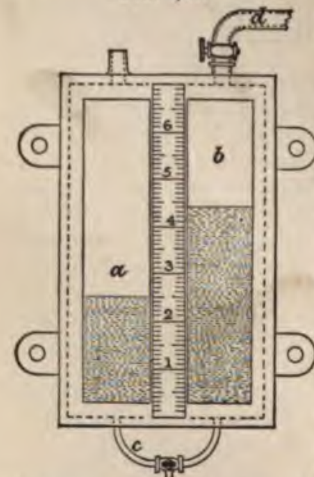
For all ordinary purposes, the velocity can be determined by holding the anemometer out at arm's length and moving it slowly over the section of the gallery, following the course indicated by the dotted line in Fig. 400.

Barometer and Thermometer.—At every mine a barometer and thermometer have to be placed. The former indicates the pressure of the atmosphere, and as the volume of air varies inversely as the pressure, the rise or fall in the barometer influences the volume of air in the mine. It is also contended that if the barometer falls, a certain amount of pressure is taken off the face of the strata, and that the gases contained in the coal are more freely liberated, or, that any accumulations contained in old goaves may be liberated. There does not appear to be much ground for this assertion, as the gas in coal exists under such a pressure that the small variations occasioned by difference in height of the barometer are unappreciable. In addition, a barometer is by no means delicate enough to act as a forewarning instrument; since such a light substance as air or gas would be affected long before any indication of change is given by a mercury column.

The indications of the thermometer are valuable, as they point out the expansion in the air current; for, as the volume varies directly as the temperature, a rise means that a smaller weight or quantity of air will enter into the mine in a given time.

Water Gauges.—For measuring the pressure producing ventilation, water gauges are employed. A cub. ft. of water at 62° F. under 30 inches barometrical pressure, weighs 62.355 lbs., so that the pressure per sq. ft. due to each inch in height is consequently $\frac{62.355}{12} = 5.196$ lbs., but in ordinary calculations it is usual to take one inch of water gauge as being equal to a pressure of 5.2 lbs. The ordinary form consists of a U-shaped tube, with one end open to the atmosphere, and the other placed in communication with the return air-way of the mine. As the presssure of air inside the mine is smaller than that outside, the weight of the atmosphere depresses the column in one leg of the tube and raises it in the other. The difference in height is measured by a movable scale, graduated in inches, and indicates the pressure producing ventilation.

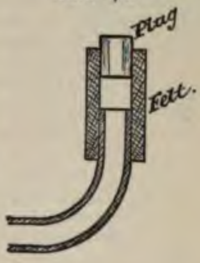
FIG. 401.



The variations in the pressure which are constantly going on with centrifugal ventilators cause considerable oscillation of the liquid in the tubes, and, in addition, capillary attraction causes the surface of the water to take a curved line. It is, therefore, difficult to take accurate observations with the ordinary water gauge. The author has adopted a form (Fig. 401), the design of which is due to Messrs. Atkinson & Daglish. In it the two tubes are replaced by two large compartments, *a* and *b*, having sheet glass in front. These are connected by a very small copper tube, *c*, in the centre of which is a three-way cock. One compartment is closely sealed, and connected by means of a pipe, *d*, with the fan drift, while the other is open to the atmosphere. Owing to each compartment being of large area while the connection between the two is very small, the column of the water remains quite steady and capillary attraction is not noticeable. A movable scale serves to determine the difference in level.

Considerable difference of opinion exists as to the proper position to take the water gauge at, and in which direction the end of the tube should be placed respecting the current. The English Fan Commission take the gauge 6 ft. from the entrance to the fan inlet. This appears to be open to the objection, where small high-speed fans are used, that the eddies produced by rapid revolution are likely to give false results so near the machine. The general opinion is that the end of the pipe going to the water gauge should be placed at right angles to the air-current and preferably covered loosely with a roll of felt plugged at the top with wood, to cause the air to pass through the cloth (Fig. 402).

FIG. 402



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APPENDIX.

Table showing the Specific Gravities, Molecular Weights, &c., of Various Gases.

	Symbol	Specific Gravity.	Weight of 1000 c. ft. at 0° C. and barometer 760 m.m.	Molecular Weight.
Air		1.000	80.712 lbs.	
Nitrogen	N	0.9713	78.395 "	
Oxygen	O	1.1056	89.235 "	
Carbonic Oxide	CO	0.9678	78.113 "	12+16=28
Carbonic Acid	CO_2	1.52901	123.409 "	12+32=44
Marsh Gas	CH_4	0.559	45.118 "	12+ 4=16
Sulphuretted Hydrogen	SH_2	1.1749	94.828 "	32+ 2=34

CHAPTER XII.

LIGHTING.

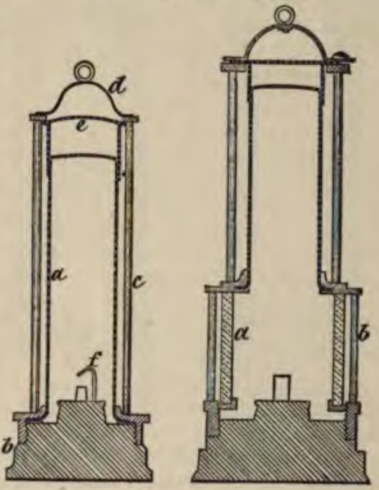
Naked Lights.—The original and most successful method of lighting the miner at his work was to employ the ordinary tallow candle, or small oil-lamp. The illumination given is far better than that of any enclosed lamps; indeed, naked lights are so superior in this respect, that the inducement to use them sometimes oversteps discretion. In some mines, fire-damp is found in small quantities, and through using naked lights accidents happen at rare intervals. To secure the maximum safety the enclosed type of lamp should be adopted, but it is an open question whether, owing to the smaller amount of light yielded, the increase in the number of accidents from falls of roof and sides will not more than counterbalance those due to explosions, because even with safety lamps absolute security is not obtainable. Miners much prefer working at collieries where naked lights are used.

Ordinary tallow candles of 16 or 18 to the lb., of the proper hardness to withstand the heat of the mine, are the common illuminant in non-fiery seams. They are usually stuck in a ball of clay, which allows them to be attached to timber or coal in any required position. In Scotland a small oil-lamp is very largely employed. It gives a good light and can be carried about easily, but cannot be attached to the timber or sides in the same ready way that a candle can.

SAFETY LAMPS.—At the beginning of this century so many accidents took place through the employment of naked lights, that an attempt was made to devise some arrangement for insulating the flame of a lamp, and for preventing it from producing an explosion in the surrounding atmosphere.

Davy's Invention.—Perhaps what might be called the first safety lamp was that invented by Dr. Clanny, in which a current of air was passed into a lamp through a stratum of water below, while the products of combustion escaped through a similar layer of water at the top; but to Sir Humphry Davy belongs the credit of not only designing the first safety lamp in a practical form, but also of discovering the principle which is still retained, and which forms the main element of security in every modern safety lamp. He found that an explosion would not pass through small apertures and tubes, and before the close of the year 1815 gave to the world a wire-gauze lamp. The Davy lamp (Fig. 403*), as originally and still constructed, consists of a cylindrical gauze, *a*, screwed to a brass ring, which, in its turn, is attached to the oil vessel, *b*. The gauze is protected from accidental blows by three iron pillars, *c*, passing upwards from the brass base to an annular ring at the top, to which is further attached a metal cap or hood, *d*, above which a loop is placed to enable the lamp to be carried about. As an additional security, a second cylinder of gauze is attached at the top of the first one forming a cap, *e*. To trim the wick and to regulate its height without opening the lamp, a thin piece of wire, *f*, called a "pricker," passes up a closely fitting tube through the oil vessel. The gauze should not contain less than 784 apertures to the square inch.

FIGS. 403 AND 404.



Clanny.—In this lamp a portion of the gauze of the Davy is replaced by a glass cylinder, *a*, protected by metal bars, *b* (Fig. 404). The other arrangements are similar to the Davy. The feed-air which supplies the flame has to enter the lamp above the glass, and hence gets mixed with the products of combustion, the result being that the light afforded is very little superior to the Davy.

Stephenson.—The celebrated engineer, George Stephenson, then at Killingworth Colliery, was experimenting upon safety lamps simultaneously with Sir Humphry Davy, and indeed constructed one where the ingoing current was passed through small tubes. As soon as the wire gauze was proposed, he adopted it in his lamp, which then took the form shown in Fig. 405. A cylinder of glass, *a*, is placed inside the wire gauze, and is covered over by a perforated copper cap, *b*. The feed-air is admitted through a number of small perforations, *c*, below the bottom of the wire gauze and glass cylinder. If the lamp is to burn well, it is very necessary that these small perforations should be kept free from dust, which is rather a difficult matter.

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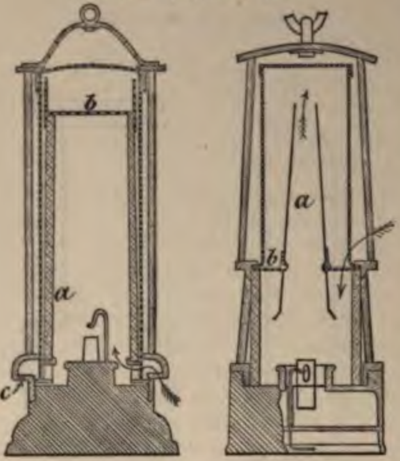
* In all the lamp illustrations, the various parts are shown thus :—

as ▨ *Brass* ▨ *Thin Sheet Metal* ——— *Gauze* ———

FIGS. 405 AND 406.



Mueseler.—This lamp resembles the Clanny, as it consists of a glass cylinder at the bottom and a wire gauze one above, but its main feature is the introduction of a central metal chimney, *a*, supported by a horizontal gauze diaphragm, *b*, placed at the top of the glass (Fig. 406). The products of combustion pass up the chimney and induce a strong draught so that the feed-air is drawn smartly down on to the flame, and produces good combustion. This lamp, by a Royal Edict in 1876, is alone permitted to be used in the fiery collieries of Belgium, and only three modifications of a typical form are allowed. The total height of the chimney must be 4.6 inches, it has to have 3.55 inches of its height above the gauze diaphragm, and its base must be 0.85 inch above the top of the wick tube.

Design of Lamps.—The modifications introduced into safety lamps have all been with a view of rendering them safer in currents travelling at high velocities. Davy himself pointed out that his lamp should be guarded by a shield when exposed to a rapid current of explosive air, as if not, the flame would be forced through the gauze. The safety is also due to the fact that the small holes offer such a large extent of cooling surface, that when the flame impinges on the gauze, the heat is conveyed away so rapidly and the temperature so reduced, that flame cannot pass from one side to the other. If the gauze becomes hot, it loses its power of isolating flame, and hence it is most important that gases should not be allowed to continue burning in the lamp, or they will inevitably ignite the external atmosphere.

Experiments made in this country and abroad, determined that the Davy lamp would pass flame if exposed to a current having a velocity of 8 ft. a second, and that none of the other lamps just described were safe if the velocity exceeded 12 ft. a second, with the exception perhaps of the Mueseler, which has a slightly higher limit, if the current meets the lamp horizontally, but it passes flame far more readily than the others, if the current strikes it obliquely. Although this danger was often pointed out, no official action was taken in the matter until the Royal Commission on Accidents in Mines reported that such was the case, and the result of which is that the Coal Mines Regulation Act, 1887, contains a clause (General Rule 9) which practically prohibits the use of the lamps just described in the form illustrated. At the same time, such lamps form the basis of all the modern ones, but the latter are safeguarded by the addition of shields.

It should, however, be pointed out that something more is needed in a safety lamp than the fact that it is safe in explosive currents of high velocity. Experiments at the surface are carried out with lamps perfectly clean; the experimenter's hands are in the same condition, the currents to which they are exposed are of high velocity and are composed of fresh air mixed with gas, while coal-dust is conspicuous by its absence. Underground, the conditions are essentially different; no matter how high the velocity is in the gate-roads, it is considerably reduced when it passes into the working place; powder smoke hangs about, and small quantities of carbonic acid gas are mixed with the air current. From the nature of his avocation, the miner's hands are by no means clean, he handles lamps in a rather rough-and-ready style, with the result that dirt and grease are transferred to them. Coal-dust also clogs the inlet holes and gauze. It therefore follows that the behaviour of some of the modern types of safety lamps after they have been some hours underground, and in the return air current, is not what one would desire. This, however, is exactly what might be expected from the nature of the conditions which the lamps are constructed to withstand. In order to be safe in the highest velocity of air current, they must be enclosed in one or two shields, and the inlet area for feed-air must be reduced to the smallest dimensions. So long as they are clean, and remain in a strong current, the requisite amount of air for proper combustion is delivered to the flame, but when the velocity is small and the lamp gets dirty, or is used in impure currents, the light given is of a very inferior character.

Another point of considerable importance is that demonstrated by Mr. Marsaut,* and confirmed by several other observers, that every type of lamp facilitates more or less easily the passage of flame resulting from an internal explosion. It is necessary that a certain relation should exist between the volume contained in a lamp and the surface open for the escape of the products of combustion resulting from the internal explosion, as experiments proved that exterior explosions or the ignition of the mixture outside the lamp were more rare as the open surface of the gauze was enlarged.

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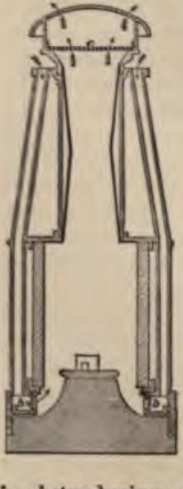
* Soc. Ind. Min. (2e Série), xii. 321; translation in Ches. Inst. xii. 179.

Mr. Marsaut proved that—(1) A small diameter lamp (such as a Davy) does not readily pass an explosion, as the volume susceptible to explosion is insignificant. (2) A lamp without a glass is more secure against the effects of internal explosions than a lamp with a glass cylinder, as the glass in the lamp confines the gases there at the time of an explosion and acts like a cannon; it is therefore both advisable to reduce the height and diameter of the glass. (3) A wire gauze of conical shape of the same capacity is more secure against the transmission of internal explosion than is one of cylindrical shape. (4) Gases resulting from combustion play a certain part in preventing external explosions, and it might therefore not be advisable to guide them by a chimney. (5) A descending current of feed-air prevents the filling up of glass lamps with an explosive mixture, and occasions the formation of an unexplosive and elastic cushion at the bottom of the lamp.

MODERN LAMPS.—In describing some typical forms of lamps, the remarks concerning them must be taken as applying to their behaviour in practical working underground. Only such lamps are referred to as have been proved by numerous experiments to be safe in all velocities which ordinarily occur in coal mines. As previously stated, this is not the only point required in a lamp. Knowing them to be safe, the great thing is to select some form which will keep burning all through the length of a shift, and which will also detect gas in small quantities quickly and distinctly.

FIG. 407.



Hepplewhite-Gray.—The Report of the Royal Commission on Accidents in Mines first drew attention to the original form of this type. The lamp then reported on so favourably is so different in construction to its modern representative that the drawing of it is reproduced in Fig. 407, with a view of clearly showing the successive developments which have taken place. Its chief peculiarity (and in which it differs from all modern safety lamps) is the admission of free air from the top down four tubes, and through an annular chamber, *b*, situated immediately over the oil vessel. It is impossible for a current to rush directly down the inlet tubes, as they are protected by the projecting top of the lamp. The only gauze employed is that covering the outlet, *c*, and the annular inlet chamber. The first improvement consisted in introducing a gauze cylinder above the glass, which now took a conical form, and adding a cone to the discharge orifice. The importance of the latter cannot be over-estimated.

The outlet arrangements of most lamps are haphazard, and bear no relative proportion to the area of inlet. With the discharge regulated in such a manner the top of the gauze is kept in a bath of carbonic acid gas, and should internal explosions occur, gas will not continue burning in the lamp. Sliding shutters were also placed at the lower end of two tubes, by which means the feed-air could either be taken from the top or the base of the tubes, an improvement properly appreciated by any one regularly testing for gas.

In the form now generally adopted, three inlet tubes instead of four are used (Fig. 408). The third tube is considerably broader than the others, and acts as a reflector. The shield-plate, *a*, in the hood is made of such a size as to completely cover the inlet holes. This is an important point, as it was found that if such was not done the lamps were often extinguished in an unaccountable manner. The height of the outlet cone must be such as to just reach the level of the shield-plate, when it then occupies a position intermediate between the two horizontal rings of holes, *b b*, which are placed in the hood for the products of combustion to escape by. A row of circular holes is put in the top crown of the lamp, and is covered by a thin sheet brass plate $1\frac{5}{8}$ in. diam. To stiffen the covering plate it is crimped in three places, the crimped parts touching the crown, as shown at *c*. These improvements remove the defect of the light being suddenly extinguished from no apparent cause. The same result is obtained with the form of hood shown in Fig. 409; here the outlet cone and inlet tubes are covered by a piece of brass bent into the shape illustrated. One hole, $\frac{1}{2}$ in. in diam., serves for the escape of the products of combustion, this being protected from direct currents by a piece of sheet brass crimped as before mentioned. This shape of hood scarcely appears of such a safe character as the former one, but a large number of lamps have been constructed to this design. Another improvement which facilitates cleaning is that the ring securing the glass in position is screwed on to the vertical plate forming the air inlet chamber, *d* (Fig. 408), instead of the frame of the lamp.

FIG. 408.

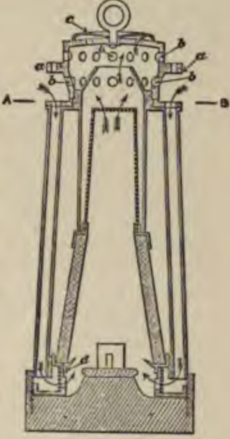
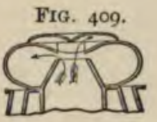


FIG. 409.



It follows from this that when the lower gauze ring is unscrewed all the inside parts of the lamp at once fall out.

In the lamp of latest design the portion of oil vessel supporting the wick tube has been lowered, but the wick tube itself has been lengthened, so that the flame is only slightly lower than in the old types. The breadth of the wick has been increased, and now stands at $\frac{9}{16}$ inch full.

The numerous small improvements, which may not separately seem of much importance, but which in conjunction materially affect the practical working, certainly make the present design superior to the earlier ones. Taking first its lighting capacity; under ordinary conditions it gives more useful illumination than any other lamp. Photometric tests conducted at the surface are misleading, for the same reasons as were referred to when dealing with velocity trials. In addition, one other fact must be pointed out. With the photometer, either when testing against another lamp or against a standard candle, the two articles are placed on the same level, and it is the horizontal rays, or those that are nearly so, which reach the screen and decide the result. Collieries require light to be thrown in all directions, especially upwards, and hence naked lights are often used under conditions which may at any time become dangerous. They are not actually unsafe, but no one can say whether they may become so. All ordinary shielded lamps suffer from the great disadvantage of giving practically no illumination on the roof. Their shields are necessarily of larger diameter than the glass, and really act like a shade, preventing any light striking upwards. The conical glass of the Hepplewhite-Gray performs just the contrary action, as it deflects the light towards the roof, and as the shield above is of smaller diameter than the lower part of the glass, nothing prevents the rays reaching the place where they are specially useful and desirable. The examination of the roof can be rapidly and satisfactorily carried out with this lamp, as the illumination given is far superior in that direction to any other design. Ordinary lamps must be tilted, and when in that position, the light obtained is of a very inferior character.

With respect to its power to detect small quantities of gas it ranks superior to all others.* All ordinary forms, with the inlet above the glass, will miss, say, 4 in. of gas lying immediately against the roof, except when they are tilted very much, and then there is great danger of their going out. Many lamps are now constructed to take air if desirable from the top, like the Gray, and then they will detect thin layers also; but even then they will not do so *rapidly*. It is possible to put some modern lamps into gas, and take them out again without any indication being given—that is to say, if it is done hurriedly. This is quite impossible with the Gray, as the flame immediately "spires" up. In comparison with the unbonneted Davy or Clanny it readily shows a cap on the flame where those lamps fail to show the slightest indication.

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* As the Pieler lamp cannot be used in ordinary every-day working it is not taken into consideration.

Numerous experiments have proved the safety of this type in currents of high velocity. The risk of internal explosions passing outwards is practically absent, owing to the small quantity contained in the lamp, the regulation of the outlet of the products of combustion, and the conditions under which feed-air is introduced. Theoretically an internal explosion is impossible, as owing to the admission being below the flame, any fire-damp is burnt as it arrives, and the inside of the lamp is filled entirely with the products of combustion; but this, however, is not absolutely the case.

A statement was once made to the author that this lamp went out so soon when introduced into gas that it was impossible to clearly ascertain whether such gas was fire-damp or black-damp, if only small quantities were present. On the other hand, he has been assured by an overman, who has specially been working and examining places with this lamp for over twelve months, that not the slightest difficulty has been experienced in this respect. With black-damp the flame drops and fades away, but if any gas is present, a slight "spiring" of the flame is immediately noticed, and this takes place once or twice before the light is lost. Of course it is possible to abuse anything. If the lamp be pushed bodily and suddenly into gas it certainly goes out before any definite indication is obtained; but if it be introduced slowly and steadily, and withdrawn as soon as gas is indicated, the light is not often lost.

Bonneted Mueseler.—This type of lamp has deservedly been held in good repute for many years, and the report of the Mines Accidents Commission on the shielded variety was very favourable. As a detector of gas it ranks a very good second to the Gray; it shows gas in a clear delicate manner, the cap produced being very distinct.

Owing to the presence of a chimney in this lamp, when it is tilted the products of combustion pass outside the chimney and foul the inlet air, with the consequent result that the light is extinguished. This, in combination with the shield acting as a shade, make the examination of the roof a matter of difficulty. This disadvantage of the Mueseler lamp appears to have been rather exaggerated, as it stands a fair amount of tilting, especially if the time during which this is done be not of long duration.

Ashworth's Mueseler, shown in Fig. 410, is one of the safest of all lamps, as it has been tested in explosive currents of 100 ft. per second without failure. It differs from the ordinary forms of Mueseler type in having a gauze chimney instead of a metal one, and the diaphragm is conical instead of horizontal, *b*. Its safety is due to the double shield employed, the inner one of which is provided with a conical outlet; the exit of the products of combustion is retarded; the upper part of the gauzes is kept in a bath of carbonic acid gas, and in case of any internal explosion, the light is immediately extinguished and the inlet air fouled. The arrows in the figure show the direction taken by the supply air and the products of combustion, and that the gauzes are protected from all violent currents. There are ten holes in the inside shield and seven in the outer one, the latter being placed near the top. A gas-testing shutter, *a*, is placed above the horizontal inlet holes near the top of the glass, and when this is closed, the feed-air is compelled to enter through the holes in the outer shield near the top and pass downwards, thin layers of gas near the roof being thereby easily detected.

FIG. 410.

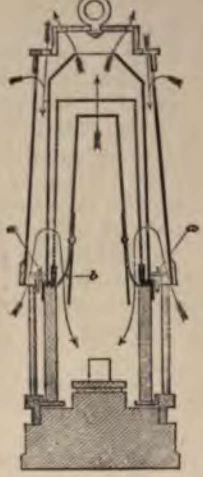
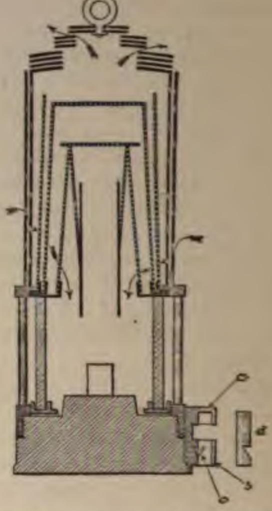


FIG. 411



This lamp does not burn well in "dampy" or slow currents, and great difficulty is experienced in lighting it, as from the winding path pursued by the feed-air, proper circulation does not take place until the lamp gets hot.

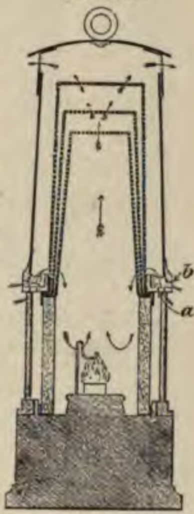
Morgan.—Prominent attention was drawn to this lamp immediately after the report of the Accidents in Mines Commission was published. Experiments showed that it would not pass flame in explosive currents of the highest velocities.

An inner and outer shield are provided (Fig. 411), the latter having a series of five horizontal rows of circular holes punched through it, while the former is similarly supplied with six horizontal rows of slits. The openings in one shield are opposite the solid portions of the other. Three gauzes are used; an outer cylindrical one without a top, a middle one of the Clanny type, and an inner one, really built up of two gauzes and a chimney.

This lamp detects gas readily, burns well in a good current of air, but badly in a "dampy" one, does not get hot (probably owing to its large internal volume), and stands a fair amount of tilting without the light being extinguished. After being in use several hours underground the light gets very defective. The author is not aware that this type has been used extensively at any colliery. It is composed of six parts, neglecting washers, and is of complicated construction. As there are many lamps perfectly safe under ordinary conditions it seems improbable that this form will come into general use.

Marsaut.—The report of the Committee of the Ellis' Lever Prize, and of the Accidents in Mines Commission brought this, then new, lamp very prominently before the mining public, and results obtained in practical use increased the favourable opinion. It has, however, received a few small modifications from the form in which it was experimented upon by the two Commissions referred to above. As originally constructed, *two* rows of inlet holes were supplied, one at the bottom of the bonnet, *a* (Fig. 412), and the other in the horizontal flange, *b*, forming the base of this part. The Accidents in Mines Commission recommended doing away with the holes in the base of the bonnet,* and in most of the lamps now constructed in this country this is carried out. In the form illustrated, three slightly conical gauzes are employed, but often two only are used. They are protected by a sheet-iron shield. After considerable experience with this lamp, the author expressed an opinion that it appeared to be the most suitable for the working miner; its construction was simple and strong, and it gave a reliable indication of gas, and a good light.

FIG. 412.



Further experience has not materially altered that opinion, as, although the lamp finding most favour does not go by Mr. Marsaut's name, yet it is practically a lamp of his type, with an addition which increases its efficiency and lighting power in the impure currents of return air-ways.

Deflector.—During an excursion in Lancashire, the author's attention was called to this lamp, and as complaints had been made of the difficulty in getting some of the other forms to burn brightly, a few lamps of this type were obtained and placed in the hands of the miners at one of the collieries under his charge.

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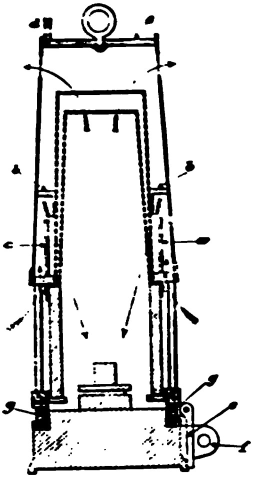
* Final Report, p. 84.

Fig. 413 illustrates the lamp, and it will be seen that the Marsaut is followed, so far as the arrangement of gauzes, shield, oil vessel, and glass are concerned. The distinctive difference, however, consists in the guiding of the inlet air; this is admitted through a row of holes in the horizontal flange, supporting the shield, and is prevented from impinging on the gauze by a vertical cylinder of brass, *a*, 1½ inches high, which acts as a guide, and directs the in-going current vertically upwards. At a point about 1½ inch above the horizontal flange supporting the shield, an angle-ring, *b*, is introduced, the horizontal part of which completely fills up the space between the outside gauze and the inside of the shield. The other flange projects downwards close against the gauze, terminating just before reaching the vertical cylinder which proceeds from the horizontal flange forming the base of the shield. It will be noticed that the vertical cylinder, *a*, is not placed close to the gauze, but occupies an intermediate position between that part and the shield. The inlet air after being directed upwards meets this "deflector," and is thus thrown on to the flame. As the lamp gets hot, more air is sucked in, and passed on to support combustion. This forms the explanation why such good illumination is obtained. At the end of a shift the light given is nearly as good as it was at the beginning. After burning a short time and getting hot, the illuminating power sensibly increases, and no difficulty is experienced in lighting the lamp when all the parts are cold.

FIG. 413.



In all ordinary lamps a rapid circulation is obtained as soon as the parts get hot, but no appliances are introduced to properly direct the inlet current, and, as a result, the greater part passes away at once with the products of combustion, only a portion going downwards to supply the flame. In the "Deflector," all the air which enters reaches the flame, and before doing so is heated by contact with the warm deflecting ring and gauzes. To this heating of inlet air and proper directing of current is due the fact that this lamp will burn in an air containing such a quantity of carbonic acid gas that all ordinary forms, even unbonneted ones, are extinguished.

The lamp is supplied with a solid top, *c*, and the shield is secured by a lead rivet, *d*. This is an advantage, as the locking of the bonnet can be left to the last minute, and until the miner has satisfied himself that all the parts are in their proper position.

Tin Can Davy.—In the North of England the ordinary Davy is enclosed in a tin case, provided with a window (Fig. 414). If this case extends the entire height of the lamp, the security afforded is greatly increased. Indeed, the Royal Commission on Accidents in Mines* stated that the addition caused the lamp to become one of the safest tested, but they also point out that at high velocities a very small difference in the form of the case, or in the position of the lamp with respect to the current, greatly affects the behaviour of the lamp.

FIG. 414

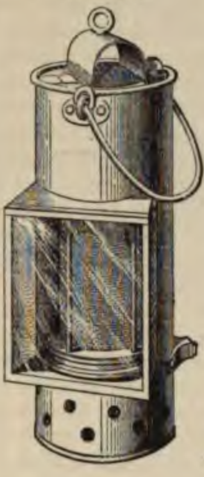
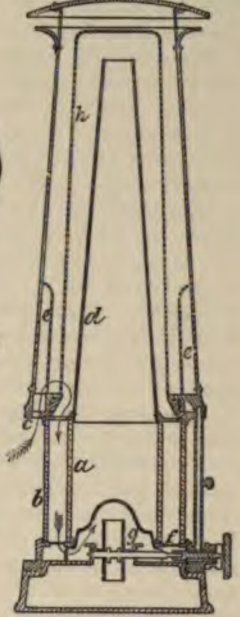


FIG. 415.



Thorneburry.—A lamp which has attracted considerable attention lately is that invented by Dr. Thorne, in which a heavy petroleum oil, having a flashing point of 250°, is burnt in a cone similar to those employed in paraffin lamps (Fig. 415). Two concentric glasses, *a* and *b*, are employed, which are not disturbed when the lamp is taken to pieces for cleaning. A metal chimney, *d*, which carries away the products of combustion, leads directly from the inner glass, while the gauze, *h*, leads from the outer glass, and as a further protection in currents of high velocity, a second piece of short gauze, *e*, is attached. The whole is enclosed in a metal shield. The feed-air enters at the point, *c*, passes down between the two glasses, and through the gauze, *f*, into the combustion chamber, *g*.

The light given is of a very superior character, and the height of the flame can be easily regulated by a pinion and milled disc. This is, however, a source of annoyance, as the small watch-key which fits on to the square shaft of the pinion very easily wears round, and just at the moment when it is wished to be put into operation, the key turns and the lowering arrangement does not. So far as safety is concerned this lamp gives excellent results, and in the hands of an official of the colliery may be used underground in strong currents of air, but it has a tendency to get very hot, especially if it stands anywhere. It is very complicated, and weighs more than any other lamp, and requires more delicate handling than an ordinary miner will give it.

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* Final Report, p. 75.

Sight Lamp.—An improvement of considerable importance has recently been introduced by the Sight Lamp Company, who employ a shield, having a great number of perforated holes through it, but which has a glass lining especially made for the purpose. In this way the shield does not obstruct the light to anything like the same amount as a solid one does. Breakages are not of frequent occurrence, as the glass is well protected by the perforated shield; there is no space between the metal and glass shield.

Conclusions.—Owing to the large amount of useful light given by the Hepplewhite-Gray, the way this is directed on to the roof, and the delicate indication of gas given by this lamp, it is preferred to all others for use by deputies, firemen, and timberers. It requires, however, very careful handling; and the light is easily extinguished even when gas is absent. Men are apt to get careless, and carry it about with the lower slide holes open, and when in that state, if the current impinges suddenly on the lamp, the light is lost. The distribution of light on the roof is due to the truncated cone form of glass, which is claimed to be stronger than a cylindrical one, and to automatically accommodate itself to sudden changes of temperature. The rapidity with which gas is detected is a great point in its favour. With this lamp it is scarcely possible to miss the smallest quantity, even when passing hurriedly from one place to another, which can easily be done with any other form, as, unless there is an appreciable quantity of gas present, they require to be held a definite time in it before any indication is given.

For the ordinary miner who requires something a little less delicate than the Gray, the Deflector lamp gives excellent results. The light given in impure air is superior to that obtained from any other form, and it will continue to burn even when the unbonneted varieties will not. It gives as good an indication of gas as any other lamp, with the exception of the Gray and Mueseler. The author obtained a number of different types of lamps for use at one of the collieries under his charge, and after an experience of two years there is not a miner at the pit who, if he had his choice, would not select a Deflector lamp in preference to any other, his reasons for this being that it burns brightly in slow and impure currents, gives a good light for a long time, and will endure a great deal of rough usage.

Oil.—The report of the Accidents in Mines Commission first drew attention to the fact that a mixture of one-third petroleum and two-thirds rape or seal oil was more suitable for safety lamps than best refined colza. It is necessary that the petroleum should be of the best quality, and that no more than the quantity given above should be used. The mixture is considerably cheaper than best colza, and gives equal illuminating power, and the wick has not such a tendency to form a hard cake on the top.

Mineral oils are but rarely employed for safety lamps, although attempts have been made from time to time to utilise them for this purpose. Benzoline is used in some of the lamps made by the Protector Company and by Wolff, of Zwickau, Saxony. It is a volatile substance and requires the greatest care in its application. No free oil is allowed to remain in the oil vessel, which is filled with a sponge, and as the wick itself does not burn an asbestos one is provided. In filling the lamp a small quantity of benzoline is poured into the vessel and the sponge saturated, all excess is then emptied back again into the tanks. It certainly gives a nice clear light and produces no smoke, but requires so many precautions in the filling-room that it has never been largely employed in this country. A special charging apparatus has to be provided, and no naked lights can be introduced into the room where the lamps are replenished. The employment of mineral oil is not allowed in the fiery mines of Belgium.

Wick.—In the lamps of recent introduction, flat wicks are invariably employed. The illuminating power of the old forms of safety lamps, when the wick was round, varied from 0.3 to 0.5 of a standard candle, but where a flat wick is employed it may rise as high as 0.7. With a view of further improvement Mr. A. H. Stokes has introduced a wick tube which is guttered along one side and the wick is supplied rather wider than the tube, so that it takes a corrugated form. A longer surface of flame is obtained and the supply of oil to the wick is better. Mr. Ashworth obtains a similar result by making the wick wider than the wick tube and the tube broader than the wick.

A point to which little attention has been drawn is the material of which the oil vessel is constructed. In England it is invariably made of brass, while on the Continent it is just as regularly made of iron. Mr. Marsaut's experiments proved that the lighting power is influenced by the material of which the lamps are constructed, and that a brass lamp only gave 70 per cent. of the luminous intensity of the same lamp in iron. The explanation of this seems to be found in the superior heat conductivity of the former, as the lamp bottom gets very hot and the oil becomes viscous. Brass oil vessels seem to be cheaper than if made of iron, owing to the ease with which they can be cast. To remove the objection Mr. Ashworth coats the top of his oil vessels with a bad conductor of heat (tin).

Glasses.—Glasses having their edges polished are now more extensively used than any other form. It is very important that all gaps should be closed, and therefore the edges must be ground approximately parallel, for if they are chipped, or not parallel, no matter what washers are used, some opening is left. Asbestos mill-board washers should always be introduced between the parts where metal and glass meet. Rubber and leather are liable to perish.

Locking Lamps.—The original device employed was that of a screw bolt turned by a key till its head was concealed below the surface of the metal into which it was inserted. This can scarcely be called a lock at all, as it may readily be opened by any one with an old nail.

Magnetic Locks.—In several types of lamps a lock has been designed which requires the application of a powerful magnet to open it. The general arrangement consists in employing a bolt which fits into notches in a circular plate and is kept there by a spring. When a magnet is placed in a certain position it attracts the bolt, withdrawing it from the notch, compresses the spring, and allows the oil vessel to be unscrewed. The shape of the spring and notches is such that the magnet is not necessary to enable the bottom to be screwed on.

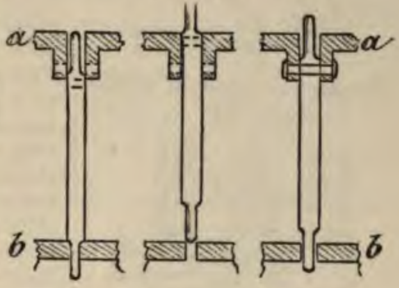
Lead Rivets.—Magnetic locks possess one advantage, that the lamp cannot be opened without suitable appliances, but they are apt to get out of order and are cumbersome. By far the commonest, and indeed the simplest, method of securing safety lamps is that of employing a pin of lead, which is riveted into place and has a device punched upon it. It is impossible to open the lamp without breaking this pin, and although, of course, any one so desiring can open the lamp, it cannot be done without detection. The common locking arrangement is illustrated in Fig. 413, and is performed by a hasp, *e*, dropping over a projecting boss, *f*, through which a hole is bored for the reception of a lead rivet. The hasp, *e*, is fitted to a loose collar, *g*, surrounding the oil vessel, which can easily be turned round, giving compensation for the wear on the screw and the oil vessel, and enabling the projection, *f*, and hasp, *e*, to be always brought exactly together.

The locking arrangement of the Morgan lamp possesses several points of novelty. Two projections, one on the oil vessel, the other on the upper part of lamp, with vertical holes, are provided, *a* and *b* (Fig. 411), but the passage in the upper projection does not go completely through it. A small spring catch, *c*, is situated in the lower projection and will allow a cylinder of equal diameter to the hole to pass by if the direction of motion be vertically upwards. The lead plug employed, *d*, consists of a cylinder with a **>**-shaped piece cut out. To lock the lamp the cylinder of lead is pushed in through the lower hole; it cannot go out at the top, as the covering prevents it, and it cannot be drawn back again, as the small spring catches under the **>**. This arrangement seems to be an improvement on the ordinary lead rivet, as time is saved.

Ryder's Lock.—In order to allow the shield to be removed after the internal parts have been fitted together, a sliding pillar is employed, which, when the oil vessel is screwed up, projects into the base of the shield and prevents its being removed, but, on the other hand, when the oil vessel is taken off, the pillar can be pulled down a short distance, thus releasing the shield.

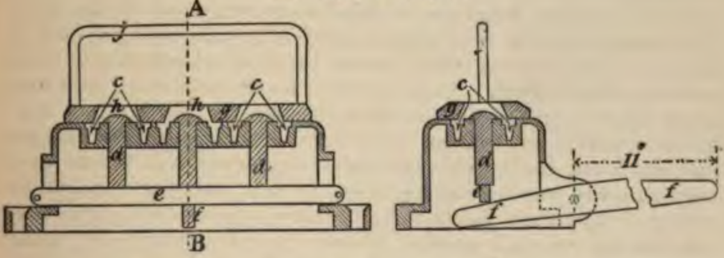
This has recently been improved; it now locks both shield and oil vessel. In Figs. 416–18, *a* is the upper horizontal ring of the cage of a lamp on to which the shield is screwed, and *b* is the bottom one that receives the oil vessel. The sliding-bar, *c*, occupies the position shown in Fig. 416 while the shield is being screwed on, and as soon as this is done, the bar is pushed upwards and takes the position illustrated in Fig. 417, locking the shield. The oil vessel is now screwed on and then the sliding-bar is *lowered* a little, its bottom end going into a recess in the oil vessel. This motion is not sufficient to take the pin entirely out of the shield, and, as a result, both shield and oil vessel are locked, and the sliding-bar is then secured in this position by a lead rivet (Fig. 418).

FIGS. 416, 417 AND 418.



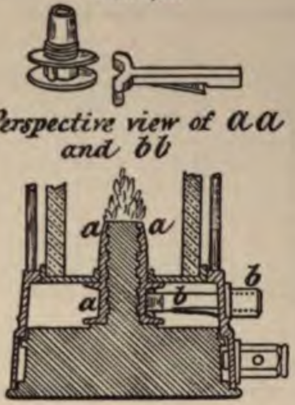
Casting Rivets.—A machine largely employed for casting lead rivets is that of Howat's, which consists of a series of recesses (*c c*, Figs. 419 and 420) of the exact size of the rivet, arranged in a circular manner around central spindles, *d d*, which have a mushroom-shaped head. These spindles can be moved vertically upwards by means of the cross-bar, *e*, and lever, *f*. The top is covered by a lid, *g g*, having holes through it at *h h*. Molten lead is poured in through these holes, and fills up the recesses, *c c*, the lid is lifted off by the handle, *j*, and by depressing the handle, *f*, the bunches

FIGS. 419 AND 420.



of rivets are raised out of their bed. To remove them from the central core to which they are attached, they are placed over a special die, and with one blow of a punch the central block of lead is detached, and the rivets are left ready for use. Each machine casts three sets of twelve rivets at a time.

FIG. 421.



Relighting Lamps.—An arrangement is sometimes provided to put out the flame if the lamp be unscrewed, but this affords no security, as it tempts the miner to carry matches about with him to relight the lamp, which may be done without detection. With the Protector lamp, however, by means of a locking bolt, after being once unscrewed the lamp cannot be relighted without unlocking. If the oil vessel (*c*, Fig. 421) is withdrawn, the wick passes down the sides of the tube, *a*, and the flame is put out and cannot again be lighted and replaced in position until the tube, *a*, is taken from the lamp and put in its proper position in the oil vessel. The tube, *a*, is locked by the bolt, *b*, which, when pushed home, is kept in position by a small spring.

The number of lamps which become extinguished from different causes in the workings is very great, and amounts, according to statistics, at many collieries to as much as 20 per cent., which have to be either relighted, or other ones served out to the men. The general practice is to provide special lighting stations, and to insist on men taking their lamps to these places when they become extinguished. Such a station must be situated at some point where a naked light is allowable, and as this is often only at or near the pit-bottom, men have to travel a considerable distance when their lights become extinguished, which acts in a very salutary way in causing them to take every precaution to prevent losing their lights. As in some mines naked lights are not allowed at all, a certain number of extra lamps are taken down, which replace those that become extinguished.

Where a volatile illuminant like benzoline is employed, a relighting arrangement can be applied. In the Wolff lamp * a strip of paper is employed, provided with fulminating spots, each of which can be brought opposite the wick by a step movement, and at the same time be struck by a trigger released by a spring; the fulminating compound explodes and ignites the benzoline vapour.

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* Man. Geo. Soc. xvii. 280.

The process can be repeated until the whole of the caps are exhausted, when the paper containing them is removed and a fresh piece put in its place.

A similar device is that of Mr. H. Elsom,* but is applicable to vegetable oil lamps. A small wire rod is fixed in the lamp on the opposite side of the wick trimmer, and carries one or more ordinary matches, which can be lighted by friction. When the light is extinguished, one of these matches is rubbed on a roughened plate and ignites, the lamp being tilted so as to bring the wick over the match. A guard plate, or shield, is fixed against the adjacent match to prevent the flame of one accidentally igniting the other.

The objection to any such appliance is, that supposing any lamp has been extinguished through the presence of an explosive mixture, when one of the matches was struck, an internal explosion would be produced which might result in the passage of flame to the external atmosphere.

Cleaning Lamps.—Where a large number of safety lamps are employed they are now generally cleaned by machinery, which consists of a series of revolving brushes fitting the several parts. To remove the oil adhering to the gauze, powdered magnesian limestone is generally sprinkled on the brushes. In some cases to obtain a similar result the gauzes are steeped at intervals in a solution of caustic potash.

FIG. 422.

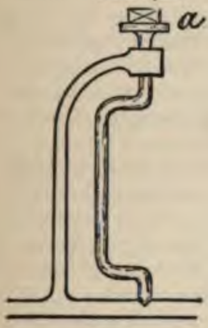
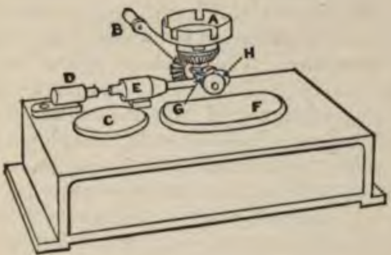


FIG. 423.



For removing the internal fittings of lamps, a simple arrangement (Fig. 422) can be employed. It consists of a nut, *a*, which fits into the projecting lugs on the lamp-glass ring, and on turning the handle this ring is unscrewed.

A more elaborate machine is that of Howat's (Fig. 423), which both rivets the lead plugs and unscrews the various parts of lamps. It consists of a cup, A, containing a number of slots, which can be rotated by turning the handle, B. The lamp bottom can be unscrewed by placing it in the cup, with the projecting boss in one of the slots, and then turning the handle. In order to remove the internal fittings, the cup A is taken off, and the lamp placed on a square nut thus exposed, which fits into the projecting lugs on the ring securing the lamp glass, &c., in their proper position. A few turns of the handle removes everything, and after cleaning, a reversal of the above operations soon puts the parts together. To rivet, the lamp is placed on the platform, C, with one head of the rivet against the stop, D, when half a turn of the handle brings the movable bar, E, forward, and locks the lamp. To unlock the lamp, it is placed on the platform, F, with the head of the rivet under the cutter, G, which on being depressed cuts off the rivet. The lamp is then removed, placed at the other end of the platform, F, and the handle, B, reversed when the eccentric block, H, pushes the rivet out.

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* Fed. Inst. ii. 35.

Electric Light Underground.—Many collieries are now provided with the electric light underground, but the system extends only a short distance from the shaft. The ordinary incandescent light, if worked direct from the dynamo, requires two conducting wires to convey the current, and as illumination is specially required in the working places, it seems improbable that the direct system of lighting as is employed on the surface will ever be used underground. The working places are naturally moving day by day, falls of roof are common, and as the space is confined, conducting wires would be quite out of place there.

Secondary Batteries.—By employing what are known as secondary batteries, or accumulators, a charge of electricity can be stored up to be given out as required. These secondary batteries consist of a series of lead plates covered with spongy lead, arranged in cells and surrounded by a solution of dilute sulphuric acid. Various elements are employed, and the cells are arranged differently by several makers, all with a view of reducing weight and increasing efficiency and luminosity. With a lamp weighing about 4 lbs., a light equal to 1 or 1½ standard candles can be produced for about twelve hours. The lamps are charged by connecting them to a dynamo, and passing in a current for from eight to ten hours, or for such a length of time as is necessary. It generally takes as long to charge as to uncharge. The lamp itself is a small incandescent one, and the light can be turned on and off by a switch.

Accumulators require constant care, even when made of large size, and still more is this the case when they are of small dimensions. During the progress of discharging and re-charging, gas is given off by the cells, and it is, therefore, impossible to hermetically seal them. A small hole has to be left for the escape of this gas, and as the cells contain a liquid, this liquid also escapes, and being an acid, attacks the connections and eats them away; sooner or later short-circuiting results. There is also considerable difficulty in determining when the cells are charged; they often appear to be so, and yet after taking the lamp underground, the light goes out in a few hours.

Primary Batteries—If some form of battery can be designed at a low working cost, which will provide in itself electricity of sufficient concentration to work an incandescent lamp, it will, no doubt, meet with considerable favour. The disadvantage of primary batteries, by which is meant a battery which is replenished by putting fresh plates and fresh chemicals into it, is that they are expensive to keep in action, as they consume a lot of material and involve considerable trouble in emptying and charging them.

Probably the most successful up to the present is that of Mr. A. Schanschieff,* which has for its elements carbon and zinc, the exciting fluid being a solution of basic sulphate of mercury in the acid sulphate, one part of the salt being dissolved in three parts of water. In one form, the elements occupy a little less than one half of the cell (the top part) and the solution a little less than the other half. The top and bottom of the lamp being hermetically sealed, on turning the battery upside down the solution flows on to the elements and the lamp begins to work. The great advantage is that no gas is given off. A second form is so arranged that the plates are electrically disconnected by lifting them out of the liquid. Lord Kelvin reports that the battery has a high E. M. F. (1.39 volts) and a very low resistance (0.15 ohm for 10 sq. inches of zinc surface). Its disadvantages are, the cost of the exciting fluid (4*s.* a gallon, although it is stated that 3*s.* 7*d.* a gallon would be allowed for the spent liquid with its solid residue and free mercury, but the loss at collieries would be considerable), and that the liquid is also exceedingly corrosive and attacks everything. The consumption of zinc is about ½ lb. in forty-eight hours.

As constructed at the present time, both forms of portable electric lights are far too delicate to be employed by the ordinary every-day miner. They will not give good results even in the hands of the officials.

Delicate Indicators.—The ordinary safety lamp will not detect a smaller amount of gas than 2½ per cent., and in dry and dusty mines it is desirable that a smaller amount than this should be discovered if present. To do this, what are known as delicate indicators are employed. Several forms are very complicated, but others exist which give good results in the hands of miners.

Pieler Lamp.†—The most successful is the Pieler Lamp. It consists of an ordinary oil vessel, but the illuminant is pure alcohol. The wick, which is composed of silk, can be raised or lowered in the wick tube in the ordinary manner. To prevent the observer seeing the flame of the burning alcohol, a conical shield is provided, covering the flame. The wire gauze is of the Davy type, but much larger, to allow for the increased height of the flame produced. In the later lamps a shield, having a door on one side, has been added as a protection, as in its original form the lamp was very unsafe even in currents of the most ordinary velocity. When moving about, the door in the shield is shut, but when an observation is being taken it is opened. With this lamp ¼ per cent. of fire-damp produces a cap of 1⅛ inches long, with ½ per cent. the cap reaches 2 inches, and when 1¼ per cent. is present the cap reaches the top of the lamp, and is of a deep blue colour. This lamp is only useful for detecting low percentages of gas, and must not be taken where gas might be present until a previous examination has been made with an ordinary safety lamp. The Pieler lamp should only be used by persons of experience and discretion.

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* So. Wales Inst. xv. 373.

† N. E. I. xxiv. 285, and Soc. Ind. Min. (3e Série), i. 299.

*Ashworth's Lamp.**—In this form, which is a modification of the Hepplewhite-Gray lamp, benzoline is used as the illuminant, which not only gives an excellent light, but when reduced and a special burner employed produces a very hot flame, which aids the detection of fire-damp. The glass of the lamp is ground dead for over two-thirds of its inner surface, and completely deadens all reflection. This materially assists the detection of the cap. It is said to give an indication of ½ per cent., and to detect gas better than any other lamp, with the exception of the Pieler. Its advantage consists in the fact that it gives a good light when not used for testing purposes. The Pieler lamp is simply a gas-tester, and another lamp has to be carried about to light the miner on his way.

Coloured Glass.—Mr. A. L. Steavenson † proposes to apply the law of the absorption of light, and employs a piece of coloured glass, which shuts off the flame of the safety lamp, and renders evident the pale blue cap in a more distinct manner than is possible with the unassisted eye. Either a slip of blue pot opal is adjusted on a lamp whenever it is desired to make an examination, or a pair of spectacles may be fitted with glass of this colour. He states that such addition is most beneficial, enabling an observer to detect the presence of gas when quite invisible to the unaided eye.

Liveing's Indicator.‡—When a coil of platinum is heated in contact with marsh gas, the combustion of the gas adds some heat to the platinum, which consequently glows more brightly than if it were in air. This is the principle which Mr. E. H. Liveing has utilised in his indicator. It consists of two coils of platinum wire through which an electric current is passed by turning the handle of a small magneto machine. One of these spirals is enclosed in a tube made air-tight and filled with pure air, the other is surrounded by a cylinder of wire gauze. One end of each spiral is provided with a glass cover, the two facing each other, while in between, a small screen, such as is used in photometric experiments, is placed. When the air of the mine is quite free from fire-damp, both spirals glow equally, and the screen would be midway between them, but when fire-damp is present, one spiral glows more than the other, and the screen has to be moved farther from it to equalise the amount of light on the two faces. A graduated scale is provided which points out the percentage of gas present due to any position of the screen.

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* Fed. Inst. ii. 352. † N. E. I. xxvi. 133.
‡ N. E. I. xxvii. 287 and xxviii. 167.

After one spiral has been heated more than the other on several occasions, its electrical conductivity becomes altered and the two will not glow to an equal extent, even when a trial is made in pure air. To allow the instrument to accommodate itself to this change, it is possible to move the zero point of the scale. After using the instrument several times, before taking it into the mine the sliding screen is moved until its two sides appear equally bright on turning the handle. The screen should then stand opposite zero on the scale of percentages, but if it does not the scale should be moved slightly until it is right, which is done by loosening a small thumb-screw that holds it. This instrument readily detects ¼ per cent. of gas, and with a little practice any intelligent person can operate it.

Hydrogen Flame.—Messrs. Mallard and Le Chatelier pointed out in 1881 the delicate indication of gas given by a hydrogen flame, as little as ¼ per cent. being clearly shown, but the difficulty of producing an apparatus sufficiently portable to be workable has only recently been overcome by the researches of Prof. F. Clowes,* from whose paper the following remarks are abstracted:

At first the hydrogen was introduced into the lamp from a small cylinder slung by a strap from the shoulder, connection with the lamp being made by a flexible tube. The maximum degree of portability is now secured by making the cylinder of small dimensions and arranging that it may be quickly attached directly to the lamp so as to form a convenient handle for supporting it. The cylinder weighs a little over a pound, and when charged with hydrogen under a pressure of 100 atmospheres it furnishes a standard flame (10 m.m., = 0.4 inch, high) burning continuously for 40 minutes. The cylinder is attached to and detached from an ordinary safety lamp instantaneously by a quarter turn. The new hydrogen-oil lamp presents the advantage of enabling any ordinary efficient illuminating safety lamp to be converted in the simplest way into a delicate gas detector, this being effected without permanently adding to its weight, the hydrogen supply being attached only at the spot where delicate tests are to be made.

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* *On the Detection and Estimation of Small Proportions of Fire Damp, Petroleum Vapour, and other Inflammable Gas or Vapour in the Air.* Journal of the Society of Arts, xli. 307. Feb. 17, 1893.

The whole proceeding of passing from the bright oil flame to the hydrogen flame, making a test and passing back to the luminous flame, can be effected in 30 seconds.

The lamp will probably be used as follows:—If the percentage of gas is unknown, the oil flame will first be reduced, and a cap looked for over it. If the gas amounts to 3 per cent., or more, it may be detected and estimated by this flame. If no cap is seen and low percentages of gas have to be looked for, the hydrogen cylinder is attached, the standard hydrogen flame obtained in the lamp, and the percentage of gas can be seen and estimated if it is between 0.2 and 3 per cent.

The hydrogen-oil lamp fulfils the primary conditions of an efficient testing apparatus; it is convenient, safe, a good illuminant, and combines delicacy with accuracy and with a wide range of indications.

Bibliography.—The following is a list of the more important memoirs dealing with the subject-matter of this chapter:

SO. WALES. INST.: *The Fire-damp Cap*, Wm. Galloway, x. 284; *Schanschieff's Portable Primary Battery*, A. Schanschieff, xv. 373; *Large Incandescent Electric Lamps* v. *Arc Lamps*, S. F. Walker, xvi. 370.

CHES. INST.: *Safety Lamps*, J. B. Marsaut (translated by W. H. Routledge and J. A. Verner), xii. 179.

MAN. GEO. SOC.: *On the Pieler Safety Lamp*, C. Le Neve Foster, xvii. 252; *On the Wolff Safety Lamp and the Contrivance for Relighting it*, C. Le Neve Foster, xvii. 280; *On a New Lead Rivet Mould*, H. Bramall, xix. 364.

FED. INST.: *Notes on Safety Lamps*, H. W. Hughes, i. 255; *Detection of Fire-damp*, J. Ashworth and F. Clowes, ii. 352; *The Thorneburry Safety Lamp*, E. B. Wain, iii. 226.

SOC. IND. MIN.: *Etude sur la lampe de sûreté des mineurs*, J. B. Marsaut (2^{e} Série), xii. 321; *Note sur la lampe Pieler*, A. Simon (3^{e} Série), i. 299.

REV. UNIV.: *Note sur les lampes electriques portatives pour mines*, E. Masson (3^{e} Série), xvi. 139.

N. E. I.: *On an Improved Method of Detecting Small Quantities of Inflammable Gas*, A. L. Steavenson, xxvi. 133; *On a New Method of Determining very Small Quantities of Inflammable Gas*, E. H. Liveing, xxvii. 287 and xxviii. 167; *Notes on the Mueseler Lamp*, A. R. Sawyer, xxix. 141; *On the Principles of Electric Lighting and the Construction and Arrangement of Electric Lighting Apparatus*, S. F. Walker, xxxiv. 3; *The Marsaut Lamp*, M. Walton Brown, xxxiv. 161; *The Pieler Lamp and Mode of Indicating small Quantities of Fire-damp*, T. W. Bunning, xxxiv. 285; *Testing of Safety Lamps: Account of Experiments made by Profs. Kreischer and Winkler*, P. Phillips Bedson, xxxv. 3; *Cuvelier's Lock for Safety Lamps*, E. L. Dumas, xxxvi. 51; *Ackroyd and Best's Safety Lamp Cleaning Machine*, Wm. Ackroyd, xxxvii. 121.

ANN. DES. MINES.: *Sur l'emploi des lampes electriques.* Report of a Commission (8^{e} Série), xviii. 699.

BRIT. SOC. MIN. STUD.: *Safety Lamps*, A. H. Leech and W. H. Routledge, vi. 119; *Heath and Frost's Shot Firing Lamp*, E. S. Hope, xi. 42; *How to Light a Colliery with Electricity*, S. F. Walker, xiii. 147.

CHAPTER XIII.

WORKS AT SURFACE.

Boilers.—The generation of steam at a colliery is a point of considerable importance. Not so long ago the argument was often put forth that coal at a colliery cost nothing. Certainly, a quantity of unsaleable mineral is produced, but this bears a small proportion to the total output. When labour was cheap, little machinery was employed, requiring only a limited quantity of steam. The tendency, however, at the present day is to do nothing by hand that can be performed by machinery, and, as a result, greatly increased quantities of steam have to be used; the consumption of coal has correspondingly increased, and in addition to the portion of unsaleable produce, the better quality of coal has also to be used. In consequence of this, fuel-saving appliances are becoming quite common; indeed, many of the more modern collieries are as well designed in this respect as any other branch of engineering.

Under the old régime, cylindrical externally fixed boilers were invariably applied, and a great deal may still be said in favour of them. They certainly do not raise steam economically, but to a great extent this failing is counterbalanced by their low cost of repairs, and the facility with which they may be cleaned from incrustation resulting from bad water. This is the chief recommendation of boilers of this type, and where the water is very bad they cannot be surpassed.

The tendency at the present day is to employ high pressure steam. Its advantages are numerous, as superiority in economy is not its only recommendation. Its use from the beginning materially affects the capital outlay at any colliery. If instead of using 50 lbs. pressure, 150 lbs. is employed, which is now becoming common, not only is the size of every engine on the place less, and the cost also, but the buildings are smaller, the size of the steam-pipes is reduced, and the whole installation can be made more compact.

The generation of high pressure steam requires tubular boilers, of which there are numerous types. That well-known form called the Lancashire boiler, which consists of a cylindrical shell, having two longitudinal tubes running the entire length, may be taken as the type upon which other designs are based. Two fires are employed, one in the front end of each flue, and the products of combustion, after passing through the boiler, are conveyed along each side, and finally returned beneath the bottom to the chimney.

In the Galloway boiler, the two main tubes in which the fires are situated, merge into one of elliptical form, in which are placed taper vertical tubes, the circulation of water and heating surface being thereby increased. This boiler is in extensive use, and for the past fifteen years has stood in the foremost rank as an efficient and cheap steam-producer.

In the Arnold boiler, a longitudinal tube extends for some distance along the flue behind the bridge, and connects the upper and lower parts of the boiler through the flue. The introduction of this tube is claimed to increase the effective heating surface and to split up the flame of the heated gases, so that more of their heat is imparted to the water. Another patented feature of this boiler is the barrel shape of the rings forming the flues. This construction gives a greater area of heating surface than the cylindrical shape and more strength.

The final division under which boilers may be classed is that of the multitubular or locomotive type, in which a series of small tubes placed longitudinally are arranged within the shell, but such class is capable of further subdivision. In one type, the hot gases pass through the tubes, which are surrounded by water; while in the other, the tubes are full of water, and the hot gases circulate on the outside. In the latter type, the tubes are placed in an inclined position and are connected with each other and with a horizontal cylinder by vertical passages at each end. The upper cylinder is kept half full of water, and steam forms in the remaining portion. Multitubular boilers have not received much favour at collieries.

All high pressure boilers should be provided with two safety valves, which are best of the dead-weight type, a common form being shown in Fig. 424. The valve, *a*, which is ball-shaped, is attached by brackets to a cylinder, *b*, upon which a number of weights, *c*, are threaded. The advantage of this construction is, that there is no fear of any of the parts rusting and sticking. Instead of employing only one set of weights, sometimes the valves are arranged in groups, the discharge aperture of each being made exactly one square inch in area.

Economical and quick generation of steam is considerably assisted by delivering feed-water into the boiler as hot as possible. The general procedure is to employ the exhaust steam to supply the necessary heat. At East Howle Colliery, Durham, the exhaust steam is turned into an old boiler. Cold water enters at the top, and is allowed to fall on to a series of horizontal trays placed one below another in step form. The feed-water is heated to 200°, and is then forced by a donkey pump into the boiler.

Exhaust injectors are becoming largely employed, these, as their name implies, use exhaust not live steam, and as they automatically commence working they can be used with intermittently running engines. The practice of bringing the exhaust steam into contact with the feed-water is open to the objection that the greater part of the oil and grease which is used in the engines is carried back into the boilers.

To overcome this, at Abram Colliery, Lancashire, the arrangement shown in Fig. 425 is employed. The exhaust steam is turned into a vertical chamber which is in free communication with the atmosphere through an opening at the top. Feed-water enters near the bottom through a pipe and is forced to circulate through a spiral tube, and on reaching the upper extremity passes by another pipe into the boilers. The exhaust steam which is in contact with the outside of the tube heats the water to nearly boiling point, and as the steam has free passage through the appliance, no back pressure is put on the engine.

FIG. 424.

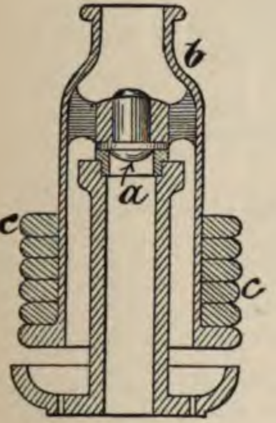
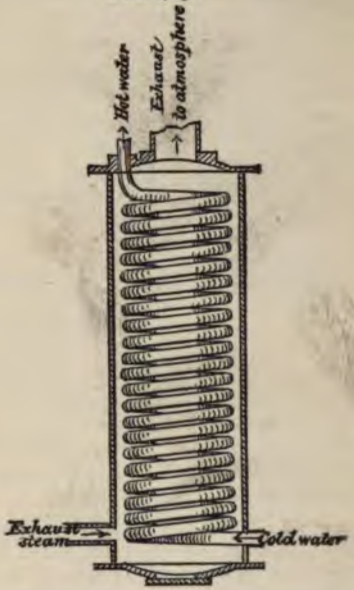


FIG. 425.



Mechanical Stoking.*—Firing by hand being a very laborious operation, numerous attempts have been made to supersede it by mechanical means, and at the present time many successful devices are in operation. They may be divided into two types—(*a*) where the fuel is fed from a hopper on to a plate, and then carried forward on to the bars; (*b*) where the coal is thrown on to the fire in small quantities at a time, by either a small revolving fan or a shovel moved by a spring.

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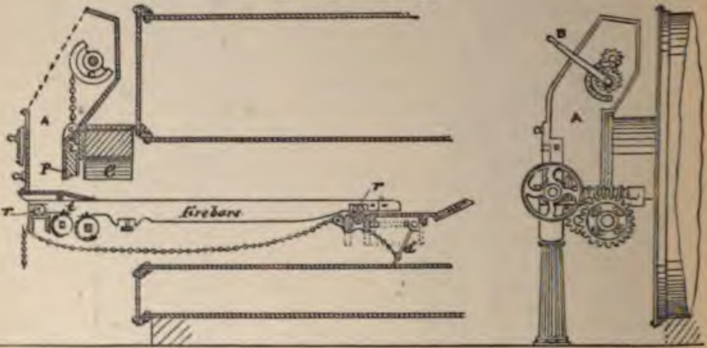
* Consult *Machine-stoking*, J. F. Spencer, Inst. C.E. civ. 55.

It may now be regarded that the claim made for such machines of using an inferior class of coal and raising steam cheaper may be conceded. With them the fire is added to by the smallest quantities at a time, and the operation is perfectly regular, which can never take place with hand firing, unless one man is kept to each boiler. A saving also results from the fact that the fire doors are rarely if ever open. Not only does this prevent smoke, but it reduces the wear of the boiler, as cold air is prevented from getting on to the hot plates.

FIGS. 426 AND 427.



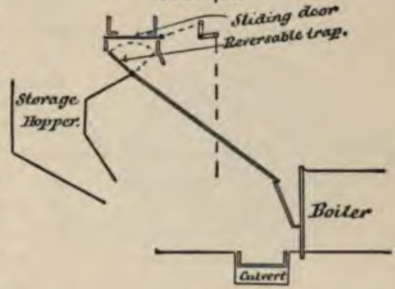
The bars in both types of stokers are movable, usually arranged to all move forward together, to carry with them the fire, and to return by ones and twos at a time, leaving the fire behind, but at the same time breaking it up. In this way the fire is gradually carried forward into the boiler, finally dropping over the bridge at the end with the coal wholly consumed.

A mechanical stoker of the coking class is shown in Figs. 426 and 427. A trough, A, runs across the front of the boiler, and the slack for consumption is placed there. The projecting ends of the movable bars form the bottom of the trough, and as they travel forward carry with them a certain proportion of fuel at each stroke. The bars run on rollers, *r r*, and are all moved forward some 3 in. at the same time by tappets, *t*, the thickness of the layer of slack carried onward being regulated by the distance between the bottom of the trough and the plate, *p*, which can be either raised or lowered by revolving the wheel, *c*. The slack passes underneath a fire-brick arch, *e*, which is red hot, and is ignited; the bars return in twos, leaving the fire where it was taken to by the forward motion.

This operation is repeated twice a minute, or as often as is desired, the rate being so arranged that when the charge reaches the end of the bars complete combustion has taken place. The clinker drops off at the end of the bars, and when fit to be pulled out is removed through the door, *d*.

Coal Conveyors.—Mechanical stokers reduce labour to a certain extent. They take off cleaning and feeding the fires, but still require manual labour to fill the hoppers, and as these are usually some distance above the ground level, their feeding requires considerable labour, as the coal has to be thrown upwards to a height of at least six feet. The advantages of mechanical stoking are, therefore, not fully realised unless some automatic means are provided for conveying the coal into the hoppers, and the economy is still more marked if, at the same time, the ashes are also conveyed away automatically. The latter is of considerable importance, because the coal employed with mechanical stokers is generally of a far inferior character to that used with hand firing, and consequently makes a larger proportion of ashes, this being especially the case when very inferior qualities are burnt.

FIG. 428.

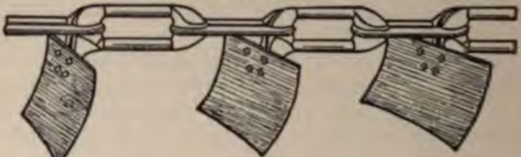


An arrangement for automatically conveying the coal and removing the ashes, as adopted at a large colliery, is shown in Fig. 428. The coal, after being freed from all large, is raised by a bucket elevator, or Jacob's ladder, and delivered on to a channel formed of iron plates, in the bottom of which, opposite each hopper of the mechanical stoker, are fixed sliding doors, which are under the control of the stoker, who can open and shut them by means of suitably arranged levers. Below each hole is a reversible trap which either directs the coal into the shoot going to the hoppers, or into a storage bin. Travelling along the channel is an arrangement known as a "conveyor," which consists of a series of plates fastened at intervals to a chain (Fig. 429). As the chain moves along, the coal is carried forward in front of each scraper, and passes down through any of the openings which are not closed by the sliding doors, and thence by the shoot into the feed hoppers.

A culvert with a similar conveyor running in it is arranged along the front of the boilers. The ashes are raked into this culvert, and are carried along by the creeper to the end, where they fall into a trough and are raised by a Jacob's ladder into a truck, and then pass away to the refuse heap.

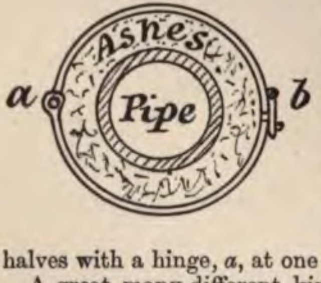
Another form of conveyor consists of a spiral revolving in a semicircular trough. If the spiral is made strong enough the appliance works very smoothly and gives good results with small particles, but unless the shaft of the spiral is well supported by bearings, it has a tendency to "sag," and soon wears out the bottom of the trough.

FIG. 429.



Coating Steam Pipes.—To prevent condensation and loss of heat by radiation, boiler houses are often roofed in, not perhaps so often at collieries as they should be. The pipes conveying steam to the different engines should also be protected by some external covering. A very good cheap kind is to bind on a series of rough wood bars all the way round the pipes. At Mariemont, the covering employed possesses the advantage of being movable. A zinc or sheet-iron tube surrounds the steam pipe, and a layer of ashes is placed between (Fig. 430). These tubes are made in halves with a hinge, *a*, at one side, and a clasp, *b*, at the other.

FIG. 430.



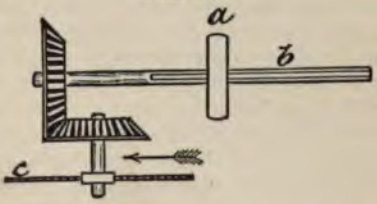
A great many different kinds of non-conducting materials for covering steam pipes are in existence. The subject has been most carefully gone into by the late Mr. W. J. Bird, who states that in an actual case the loss of steam was reduced fron 12.16 per cent. when the pipes were uncovered to 1.86 per cent. with covered pipes. The saving is increased by increasing the thickness of the covering, but this thickness has an economical limit. It may broadly be stated that the great majority of the compositions give very satisfactory results, and that the worst of them is better than nothing at all. They are liable to deterioration from damp and heat, and should be protected by a covering of tar; in places where the covering is liable to receive blows it is further protected by a layer of felt, followed on the outside by a sheeting of zinc.

Workshops.—As the great majority of collieries are situated away from towns, it is very necessary that they should be provided with mechanics' shops, either of a simple or elaborate character, depending on the size of the mine. At the largest collieries nearly everything is made on the ground, indeed, in many cases, new engines are built there, and the shops rival those of engineering establishments. At all mines a certain staff of mechanics have to be retained to attend to breakages, and if good men are to be kept, they must have regular employment. It is far better to do repairs on the spot than to send them away. Not only is time saved, but the cost is reduced, as urgency work has always to be paid for at increased rates. In all cases a small lathe and drilling machine should be put down; in the smith's shop, the fires should be blown by fans, and a steam hammer erected, this tool being perhaps the most useful about any colliery.

The practice of building and repairing railway waggons at the mine is now becoming common, and elaborate wood-working machinery is put down for the purpose. Boring and morticing machines and band saws are then required, but in all cases the introduction of wood-boring machines results in economy. If performed by hand, the operation is a most laborious one, while a small machine with revolving auger can be purchased very cheaply.

For sawing timber, either for sleepers or for props and bars, circular saws are invariably put down. For cross cutting, these are either fixed to a swinging arm and drawn against the piece of timber placed in front, or, what is better still, the arrangement shown in Fig. 431 is adopted. Motion is given to the belt-driven pulley, *a*, fixed on the shaft, *b*, in which a long key-way is cut, and through bevel gearing a movement of rotation is given to the circular saw, *c*. By means of levers, the saw can be pulled forward by the attendant in the direction shown by the arrow, cutting through the timber placed before it. The pulley, *a*, remains in its place, but the key slides in the long key-way, and the shaft, *b*, continues revolving.

FIG. 431.



CHAPTER XIV.

PREPARATION OF COAL FOR MARKET.

General Considerations.—No operation connected with mining has passed through greater changes during the past few years than that of cleaning and sorting the coal. In this country so many good coals existed that a ready sale was found for them in the state they came from the mine. Naturally the best seams were worked first, but as they became exhausted, the inferior qualities had to be mined. It, therefore, became necessary not only to adopt a more equal division into sizes, but to employ some means for removing the impurities, in order that the dirty coal in its clean state may become equal, if possible, to the good coal in its dirty condition.

The trade of the present day requires a more careful division into sizes than it did a few years ago, and for such reason the means employed to obtain such division have become much more elaborate and made to perform their work more accurately. The coal coming out of the mine has first to be emptied on to a screen, an operation which is performed by various machines called "tipplers." After passing over and through the screen, the mineral is received on travelling bands or belts, and the dirt picked out of it by attendants. It passes from the belts into shoots and thence to waggons, in which it leaves the colliery.

So long as the coal is large, the stones and dirt mixed with it can be picked out fairly easily, but in the smaller qualities where the refuse is fine, other means have to be adopted, either dry or wet cleaning, called "washing." Both methods depend on the different specific gravities of dirt and coal. In the former, a current of air is directed on to the mixed material, and blows the lighter coal farther than the heavier refuse. In the latter, moving water is employed, which has the same effect. The former has not received a very extended application, but the latter is not only largely employed, but is becoming more and more used every day.

Although it would be impossible to give here anything like a complete description of the many varied types of installations which are carried out in different countries to suit different conditions, yet the main features of the various parts of the apparatus used for coal cleaning will be considered under their respective heads, and an outline given of the way several plants are arranged.

One important point must be dwelt on at the outset—viz., that it is impossible to force the trade of any district to take a certain class of coal, and that cleaning and sorting appliances must be put down at each colliery to suit the trade of that district. What is acting very well at one place with economical results might work just as economically at another place, but if the sizes and qualities made are not suited to the trade of the second district, the result of its application would be a failure. Before, therefore, adopting anything, it is essential that the conditions under which it is working should be compared with the conditions under which it will have to work in its new situation.

Circulation of Tubs.—As soon as the tubs leave the cage at the surface, they have to be conveyed to the tipplers, and, after emptying, returned again to the pit mouth. If the screens are near the shaft, the heapstead will be covered with iron plates called "flat sheets," upon which the tubs can be turned about in any direction. A better plan is to lay lines of rails and ensure movement taking place in definite paths. The tubs can then be pushed, or the rails placed at such an inclination that the tubs gravitate towards the discharging place. As they are generally taken off the cage on one side, and put on it again from the other, if it is downhill to the tipplers, it must be uphill going back, and consequently a more or less greater expenditure of labour is required to perform the haulage, the amount depending on the size and weight of the tubs.

No better appliance has been introduced for minimising the cost of conveying tubs about the heapstead than that known as the "finger" or "creeper" chain, which was originally designed by a Belgian engineer. It consists of an endless chain travelling under the tubs, provided at intervals with vertical projecting pieces of iron (*a a*, Fig. 432) fastened to the links. The entire length of the top half of the chain rests on a girder of wood, *b*, which acts both as a support and guide. It is driven by a sprocket, or cogwheel, the teeth of which have a pitch equal to that of the chain. When a tub is conducted to the commencement of this chain, the first passing hook seizes the axle and drags on the tub, which is released at the other extremity.

FIG. 432.

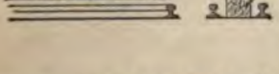
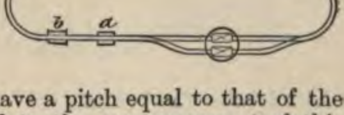
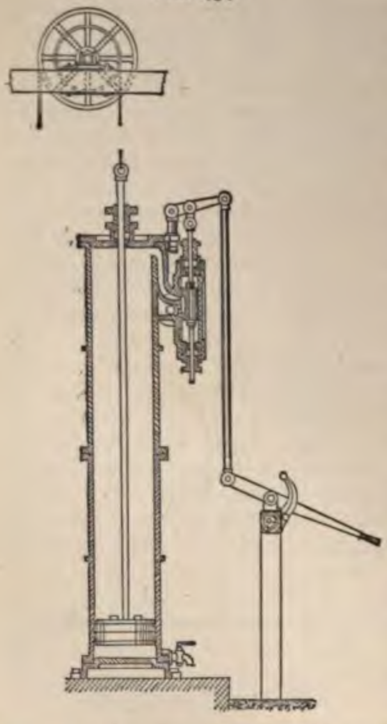


FIG. 433.



Such apparatus is generally arranged as in Fig. 433. The tubs leave the cage at the shaft, and after being weighed on the machine at *a*, gravitate to the tippler at *b*, the road being suitably inclined. The tippler is horizontal, and so placed that the tubs stop on arriving there. They are emptied, and then pushed on by the next following tub, and proceed, still by gravitation, to the point *c*; the road here is, therefore, at a lower level than the pit top. From *c* to *d* the tubs are carried along by a creeper chain, the road rising in the direction they travel, until at *d* the level of the rails is at such a height above the pit's mouth that the tubs gravitate there as soon as they are released from the chain. Any desired variation in this arrangement can be made, the common one being that instead of the tubs gravitating to the tippler they are lifted there by a creeper, and then gravitate back to the shaft. This is perhaps the preferable arrangement, as more height is obtained from the screening level to the ground.

FIG. 434.



In some cases the screening establishment is not at the pit's mouth but farther away, and the banking level is at the surface of the ground. If the screens are any distance away, the tubs can be conveyed there, and lifted the required height by any of the forms of haulage which have been described, but instead of doing this, it is common to raise them direct by an ordinary steam lift.

With a steam lift for a height of, say, 20 ft., the piston would have to be equally long, and would become not only costly but expensive to work. To overcome this difficulty a shorter piston is used, but the piston rod is connected through a rope to a small wheel keyed on a shaft, on which a larger wheel is also fixed (Fig. 434) To the latter is attached one end of a rope, while the other end is connected to a cage in which the tub is placed. The piston travelling a short distance, but attached to the smaller wheel, raises the cage a much greater distance, as this is connected to the larger diameter wheel.

After the tubs have been raised this height they can gravitate back to the shaft, but if the horizontal distance is small they attain too high a velocity, unless their progress is checked by some means. Such is done by placing wooden planks between the rails, as shown in Fig. 435, and as the tub in passing over has to depress the end, *a*, its velocity is retarded. These planks may also be placed to engage the sides of the tub.

A creeper chain as ordinarily constructed cannot work round a curve. At Clifton Colliery, instead of employing flat links as is usual, a creeper is constructed of ordinary round iron chain and works in guides, which not only govern the direction but also keep the chain down. A section through the guide is given in Fig. 436. It will be seen that only enough space is left open at the top for the projecting piece to work through. It was found that something of this kind was necessary, as the chain was continually going out of an ordinary guide open at the top.

FIG. 435.

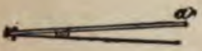


FIG. 436.

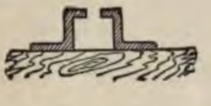
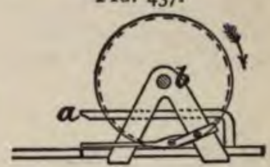


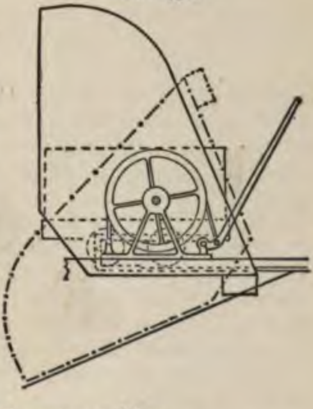
FIG. 437.



TIPPLERS.—Three classes of this machine are in vogue—(*a*) those discharging the coal forward; (*b*) where the tub is turned backwards; and (*c*) where the discharge is sideways.

Front Tipplers.—The ordinary construction is shown in Fig. 437. The tub runs on and is locked in position by the hoop part, *a*, which catches over the axles. The machine is pivoted about a centre, *b*; when the tub is full, equilibrium is unstable, and the machine turns round the centre point in the direction indicated by the arrow, emptying out the coal, the rate of turning being regulated by a brake. As soon as the coal is discharged, the centre of gravity falls below the axis, and the tippler returns to its former position.

FIG. 438.



The disadvantage of this class is the distance coals have to fall on to the screen, occasioning considerable breakage. Several devices are in use for minimising such objection. In Riggs' tippler (Fig. 438) the front is enclosed by an upright plate hinged along its upper side, and during the revolution the coal is not discharged until this plate nearly rests on the screen bars.

At Cowpen Colliery, Northumberland,* a sliding door is provided at the top of the end tipplers to prevent breakage of coal when emptying. Half the tippler is covered in with a fixed plate (*a b*, Fig. 439), the other portion, *b c*, sliding on rollers. When the tub is pushed into the tippler, the whole revolves about the axis, *d*, and no coal is discharged until the end, *c*, of the sliding door drops on to the fixed projecting stop, *e*, which pushes it open in the direction indicated by the arrow. The opening so made is small at the commencement, when the coals have to be dropped furthest, and reaches its maximum when the tub is just above the screen bars.

Back Tipplers.—With the object of reducing the distance through which the coals have to fall, back tipplers were designed. In these, the tubs run on in the direction of the arrow, A (Fig. 440), and are prevented going too far by the stop, B. By a movement of the lever, C, the catch keeping the tippler in position is withdrawn, and revolution takes place in the direction of the arrow D, the speed at which this is done is controlled by a strap brake, upon which pressure is exerted in the direction of the arrow, E, and during the revolution the tubs are kept in their proper position by the stop, F G H, consisting of two links, F G and G H, each pivoted near its centre. As soon as the contents are emptied, the tippler returns to its proper position, the catch is put on by the lever, C, and the end, F, of the second stop is depressed as indicated by the arrow, this raising the end, H, and allowing the tub to be removed.

FIG. 439.

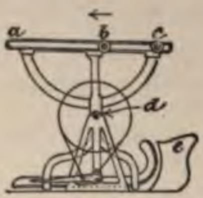
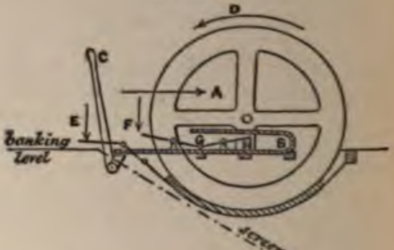


FIG. 440.



Side Tipplers.—With the tipplers just described, the coal only falls a short distance from the tub on to the screen, and breakage is small. The same result can be obtained by sliding doors, &c., applied to forward tipplers, but both have two objections, which are serious ones—(1) the tub has to leave the tippler by the same path as it went in, which occasions considerable waste of time; (2) the discharge of coal takes place from the end of the tub, which is comparatively speaking of small dimensions, and the tendency is to deposit the coal in heaps on the screen, such action being unfavourable to perfect removal of the small.

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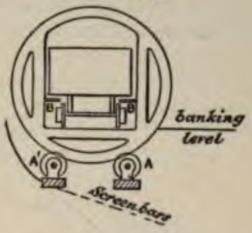
* Fed. Inst. i. 95.

To remove these disadvantages, side tipplers have been designed. They consist of two circles of iron connected together, resting on grooved wheel bearings, two of which support each hoop (A A′, Fig. 441). The tubs run in from one side of the appliance, and are supported in their inverted position by two side pieces, B B, which project over the wheels. The revolution can either be completed or return in the same direction, and the tub can either be pushed through the tippler or pulled back into the place it originally came from.

FIG. 441.



The advantages are, that if the tub comes out at the opposite end to which it enters, loss of time in manœuvring is avoided, and as the tipping takes place sideways and throughout the entire length of the waggon, the coal distributes itself equally over the whole surface of the screen. Tipping is easy, because when the tippler is in its normal position, the centre of gravity is above the centre of rotation when the waggon is full; whereas it is below after the tipping. Equilibrium is unstable when the tub is full, but stable when it is empty.

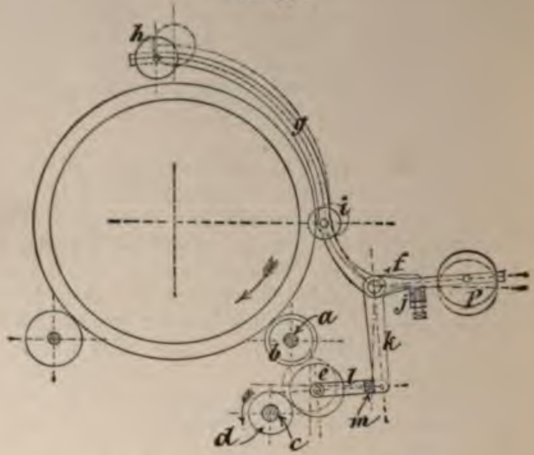
A circular plate, terminating in a movable platform resting on the bars of the screen, prevents the coal from falling during the tipping, and conducts it without shock on to the screen.

When these tipplers are revolved by hand the operation is rather slow, and, in addition, the rough unregulated movements resulting from handwork are prejudicial to the preservation of the coal. To increase the efficiency, side tipplers revolved by machinery are now used in the majority of cases. If one of the rollers supporting the tippler be made to engage with another wheel keyed on to a shaft which is constantly revolving, its motion is communicated to the tippler, which commences to revolve and discharges its contents, not with a sudden rush, but with a slow regulated movement.

The two wheels can be connected by an ordinary friction or cone clutch, which is thrown in and out of gear by an attendant. This means is used at Harton Colliery. An attendant depresses a foot treadle and throws the clutch gear into action. When the tippler has made a revolution, he moves his foot and disengages the apparatus. The disadvantage here is that the attendant has to remain at the tippler all the while it is revolving, as, if he moves his foot, the motion stops.

At Bascoup Colliery, this inconvenience has been avoided by the adoption of a friction coupling arrangement, represented in Fig. 442, which makes the tipping automatic. On the shaft, *a*, carrying the bearing rollers of the tippler, is keyed a friction wheel, *b*, and a second friction wheel, *d*, is also keyed upon the shaft, *c*, this being constantly revolving in the direction indicated by the arrow. If a third parasite roller, *e*, is put into contact with the two first by a given movement, it is clear that the movement of the shaft, *c*, will be transmitted to the hoop of the tippler, which will turn in the direction shown by the arrow. Upon the shaft, *f*, opposite to one of the hoops of the tippler, is wedged a lever, *g*, carrying a counterpoise, *h*, and a small roller, *i*, the latter being able to bind itself in a mortise cut in the hoop, and prevent the tippler from turning when in its normal position. The lever, *j*, is also keyed upon the axle, *f*. This is double, and includes the bent or elbow lever, *k*, one of whose branches carries the counterpoise, *p*. This lever can turn upon the axle, *f*, by slight friction, and can be raised by the propping, supporting, screw of the lever, *j*. The parasite roller, *e*, is bound to the elbow, *k*, by means of the crank, *l*, which cannot fall, as it is propped at *m*. This support is necessary, as when the tippler is not turning, the roller, *e*, does not touch the wheel, *a*. The counterpoise, *h*, having a greater weight than the counterpoise, *p*, will maintain it (*p*) raised when the small wheel, *i*, is in the notch of the hoop, and, therefore, the roller, *e*, will not touch either of the wheels, *b* or *d*. But, on the contrary, if the counterpoise, *h*, is raised, the lever, *k*, becomes free, the counterpoise pushes the parasite roller upon the two

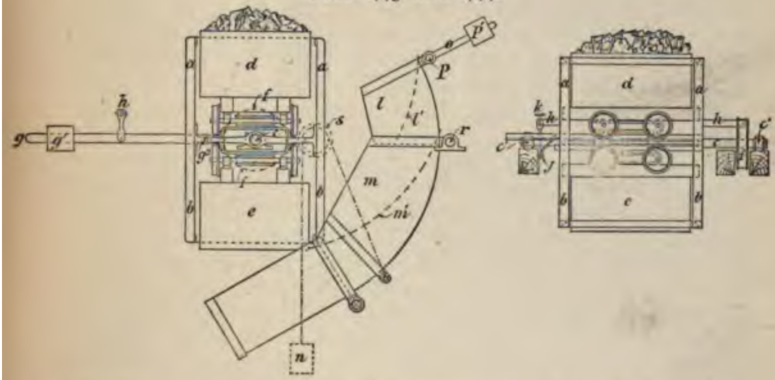
FIG. 442.



friction wheels, and the tippler revolves. The counterpoise, *h*, is not held by the workman who conducts the tipping during the whole time this takes place. He merely raises it to such an extent that the little wheel comes out of the notch, and afterwards lets go. The small wheel then runs over the hoop until it again falls into the notch, the tippler having then made an entire revolution.

The levers are placed at such an angle in their normal position that the arm, *k*, is free, and at the same time sufficient friction can be obtained on the wheels without touching the regulating screw of the lever, *j*, so that wear is taken up. The friction wheels are designed so that only the smallest pressure has to be exercised against the parasite roller to cause it to grip. An equally small effort frees it, for if at any part the **V** grooves of the wheel coincide, the points of contact change constantly, and separation is easily made. This advantage does not exist in other forms of disengaging apparatus.

FIGS. 443 AND 444.



Duplex Tippler.—Mr. Henry Fisher has introduced a tippler at Clifton Colliery by means of which two tubs are emptied each revolution. It consists of two duplicate parts, *a* and *b* (Figs. 443 and 444), placed diametrically opposite each other, and both carried by the central shaft, *c*, journalled in bearings, *c'*. The two parts, *a* and *b*, balance each other in all positions, but when a loaded tub, shown at *d*, is run on the upper part the weight turns the tippler over, empties the tub, and brings the lower part and the empty tub, shown at *e*, into the upper position, so that the latter may be removed, and be replaced by a full one.

The shaft, *c*, is provided with a brake wheel, *f*, for locking the tippler in position while the empty tubs are being replaced by full ones. The brake band is actuated by the lever, *g*, pivoted at g^2, which automatically applies the brake by the action of the weight, g^1. The outer end of the lever, g, is raised to release the brake by the lever, h, pivoted at its centre, connected at one of its ends to the lever, g, and at the other end to a lever, j. The latter turns about a centre at one end, while the other is connected to a foot treadle, k, which can be depressed by the attendant.

The chief advantage claimed for the appliance is that the speed of tipping is greater than with machines of ordinary construction, as one tub is emptied for each half revolution. This advantage can be obtained with any side tippler by constructing it to hold two tubs, end to end; appliances of this type are by no means uncommon, indeed, at the No. 3 pit, Lens Colliery, a side tippler is in use holding four tubs, all of which are emptied by one revolution.

A disadvantage of the machine, as at present constructed, is that the tubs have to be withdrawn by the same way as they go on to the tippler, occasioning loss of time in manœuvring. In addition, the revolution is effected by the weight of the loaded tub, and is more or less a rapid, unregulated one, tending more to *throw* the coal out of the tub than to empty it. Machine-driven tipplers are certainly preferable with tender coal.

The latter disadvantage is, to a great extent, removed by an excellent arrangement of a balance-shoot. The upper end of the shoot is formed of transverse segments of convenient lengths, arranged so that their inner surfaces form a curve approximating to that described by the tippler. The two segments, l and m, are carried by the shafts, p and r. The segment, l, is counterweighted by the weight, p', at the end of the lever, o, and m by a weight, n, connected to a chain passing over the pulley, s. By the action of these counterweights the segments, l and m, take the position shown by dotted lines at l' and m' when they carry no load. When the tippler is overturned, the segments, l and m, break the fall of the load until this overcomes the action of the counterbalancing weights, p' and n; the segments than recede from the tippler, and permit the mineral to pass down the shoot.

SCREENS.—The old type of screen consisted of a number of bars placed side by side, at equal distances apart, at such an inclination that the coal, if emptied on to the top portions, slides down the bars to the lower end, and during its passage the fine is removed. The width between the bars depends on the size of the coal to be made. The form of the screen bar is of importance. They are often made of a simple rectangular section, but bars of this form possess no advantage. They soon become choked up, and do nothing to direct the coal into the apertures. After considerable experience the section shown in Fig. 445 has been adopted at Bascoup. The top of each bar is triangular-shaped; the two sides are parallel for a short distance, and then converge towards the centre. The triangular ridge on the top directs the pieces of coal into the openings, and as soon as any piece gets a short distance through it readily falls away, for the space between the bars gradually gets wider.

If large quantities are to be dealt with on ordinary fixed bar screens, the screens either have to be placed at a high inclination, or increased in number, and the slope made less. In the former case separation is not only imperfect, but the coal travels at a high velocity, especially towards the bottom of the screen, with the result that it is not only broken on the screen, thereby increasing small, but with a tender coal, a further breakage results in passing into the waggons, sometimes producing as much slack as is taken out by the screen. The velocity may be either reduced by decreasing the inclination, or by placing movable doors at certain points, an ordinary form of this being shown at Fig. 446.

FIG. 445.

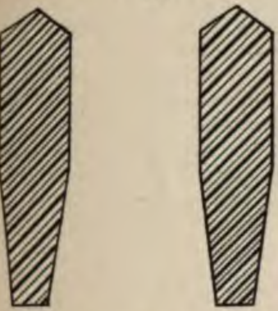
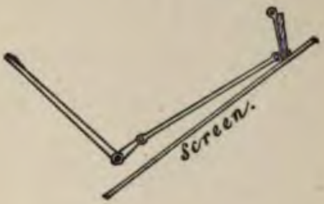


FIG. 446.



The effect of reducing the velocity is to diminish the quantity passing over each screen, and to increase the cost of cleaning, because a larger amount of labour is required to assist the screening by raking the coal over the bars. For such reasons screens worked by mechanical power have received extended application during recent years. Either the bars may be movable, or the entire screen may receive a reciprocating motion.

Movable Bar Screens.—A simple but effective device for increasing the sorting capacity of bar screens is that adopted at Brinsop Hall Colliery, where an up-and-down motion is obtained from two eccentrics, having a throw of about 8 in., one being fixed on each side of the screen. The screen consists of two sets of bars arranged alternately, one being fixed, and the other movable. The movable bars are about 4 in. longer than the fixed ones, and while the top ends of the latter are bolted to the framework of the screen, the former are fastened to a cross-piece of iron, the ends of which are turned and rest on a lever. This lever turns about a centre at its lower end, but the top portion rests on the eccentric, so that during the revolution of this eccentric, the lever is alternately raised and lowered, carrying with it the movable bars.

FIG. 447.

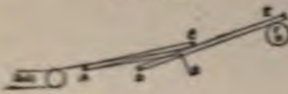


Fig. 447 shows the arrangement. All the lower bars are threaded on the spindle, A, the fixed ones are secured at B, while the movable ones project above, and are fastened to the bar, C, which rests on the lever, D E, working about the fixed centre, D. By the motion of the eccentric, F, the movable bars are raised, but only to a proportionate extent, as the bar, C, is fixed about 15 in. from the fulcrum of the lever.

The most successful screen of this class is that employed so largely on the Continent, the design of which is due to Mr. Briart. In its original form it consisted of alternate rows of fixed and movable bars, which when at rest lay in the same plane. All the movable bars were fixed in a framework, carried at its lower end by two cranks, at its upper extremity by two eccentrics keyed on a shaft, to which a rotary movement is given. The arrangement was so constructed that during the first half of the revolution of the eccentric, the movable bars were carried forward *above* the fixed bars, while in the latter half of the revolution they returned *below* the fixed bars, the result being that the coal when tipped on to the screen was lifted by the movable bars and carried forward a distance equal to the throw of the eccentric, and then rested on the fixed bars while the latter half of the stroke was being made.

To increase the capacity of each screen, both sets of bars were soon made movable, this being effected by driving each set by eccentrics keyed on shafts 180 degrees apart, with the result that each set of bars not only moves backwards and forwards, but one set is above the other when moving forward, and below when moving back, while at the beginning and end of each forward motion they are level.

The screen as at present constructed is shown in Figs. 448, 449 and 450, which are respectively a side elevation, plan, and cross section on line *a b* (Fig. 448). It consists of two sets of bars, A and B, threaded on shafts, D D. The driving shaft, C, is cranked at two points, and two links, G G, are provided, one being connected to bars, A, and the other to bars, B. These links are suspended at the far end, as shown in Fig. 448. Distance shafts, F, are provided for the purpose of keeping the driving levers, G, properly spaced, and, in addition, it is to one of these shafts that the central bar of the screen is wedged, when the construction is such that the distance between the bars is capable of variation. Fig. 451, which is a reproduction of a photograph of a model, clearly shows the two sets of bars, and the way they are connected to the driving levers.

The great advantages of the Briart screen are: that it may be

FIGS. 448 AND 449.

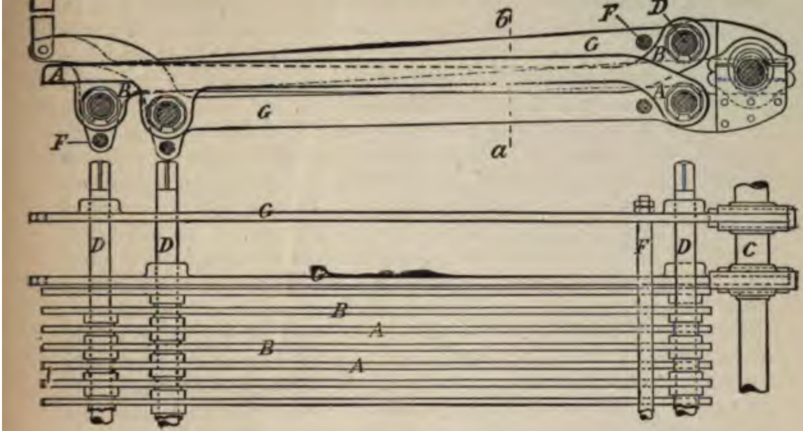


FIG. 450.

Section on a b

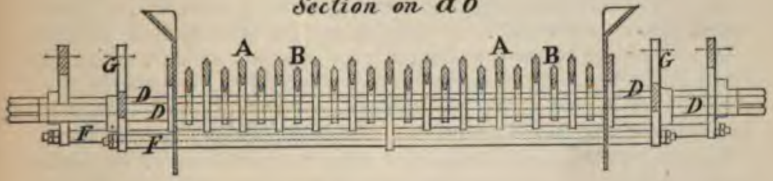
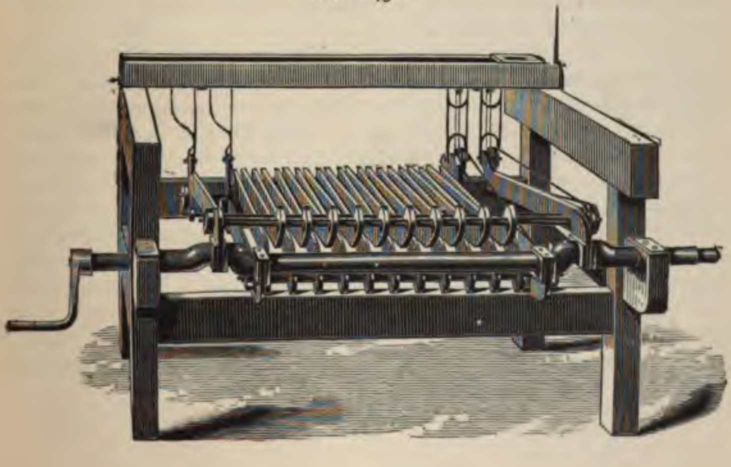


FIG. 451.



placed horizontal, thus diminishing the height of the heapstead; by regulating the speed of the driving shaft the quantity passing over them can also be varied within certain limits, as the coal is moved forwards double the throw of the eccentrics for each revolution; manual labour is diminished; in addition, as the bars have an up-and-down motion, the coal is shaken throughout its mass, and perfect removal of the small is obtained.

Its only disadvantage is that common to all bar screens—*viz.*, that the longitudinal slits between the bars allow long thin pieces of coal to pass through, and such perfect sizing is not obtained as is given by a sieve made of wire netting. In the form constructed in Germany even this objection has been removed, as the bars, instead of being formed of strips, are made of channel iron, having perforations in the horizontal side. At Bascoup, the driving eccentrics originally employed have been replaced by elbows, which absorb less work. The two systems of bars are movable, and driven from the same axle, on which the elbows or knees are keyed diametrically opposite each other. This modification, previously employed in Germany, allows the stroke to be diminished by one-half, and to balance one system of bars by the other.

Jigging Screens.—Reciprocating screens are easily and cheaply constructed, and size the coal very completely. They consist generally of woven iron netting carried in a frame and suspended from stays, two on each side. A rocking motion is imparted to the whole structure by means of eccentrics keyed on a shaft, which is revolved by a small steam engine (see Fig. 478). In general the direction of motion is the longway of the screen, but in others it is sideways. As the travel of the coal is assisted by the shaking, a jigging screen can be placed at a smaller inclination than a fixed bar screen, but the slope must be steeper than with the Briart screen. Instead of wire netting, plates having holes punched through them are used, and if these holes be circular instead of square the sizing is perfect.

Recently Mr. E. B. Coxe* has designed a screen which receives a gyratory motion similar to that of an ordinary hand sieve. The chief problem was to support the screen in such a manner that it will gyrate easily and safely, and at the same time to counterbalance the centrifugal force and prevent its shaking the building. This has been done successfully by a method which consists essentially in supporting one horizontal plate upon another by means of three or more double cones (Fig. 452), while the motion of gyration is given to the upper plate by a crank, *a*, upon a shaft passing through and journalled in the lower plate. The cones roll freely in a prescribed path on the lower plate, while the upper plate moves upon the other end of the double cone.

These cones are guided in various ways, but when the screens are run at high speeds there is a tendency in the double cone to fly from the centre, and the surface in such case on which the cones roll is made conical, so that the weight of the screen has a tendency to force the cone towards the centre, thus counteracting the centrifugal force to a great extent.

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* Amer. Inst. M.E. xix. 398.

FIG. 452.

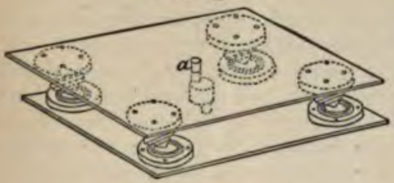

FIG. 453.

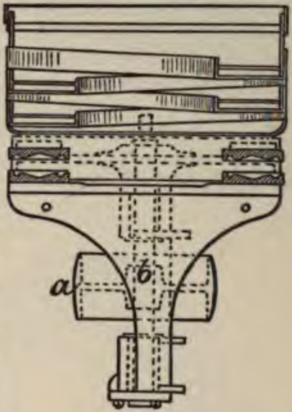

Fig. 453 illustrates the appearance of a single gyrating screen. The lower plate of Fig. 452 has here become a box bed-plate, and the upper plate a screen box, provided with a number of trays, one above the other and inclined as shown. A pulley, *a*, is fixed to the shaft, *b*, above which is a crank driving the screen box.

Revolving Screens.—Instead of giving the screen a reciprocating motion, cylinders revolving about an axis are often employed. If the openings between the bars, or the mesh, if the cylinder is of wire gauze, vary through different lengths of the cylinder, several sizes can be made on one of these screens. They are rarely employed for large coal as their capacity is small, only a few inches of the circumference being at one time in action. If any quantity is passed through, the screen becomes overcrowded and acts like an elevator, lifts the coal a part of the way up the sides and throws it back into the screen, producing a considerable amount of small. For separating the smallest sizes, as required for coal washing, such screens are, however, largely employed.

Spiral Screens.—In the coal districts of Germany a spiral revolving screen is used with success.* It consists of a long strip of plate, perforated throughout its length with holes of different sizes. This strip is wound into a spiral, and the ends closed and mounted on a shaft. Their diameter is greater than their length, in some cases nearly double, and screening is often assisted by blows from a wooden hammer, or jerks from springs. The construction will be understood from Figs. 454 and 455.

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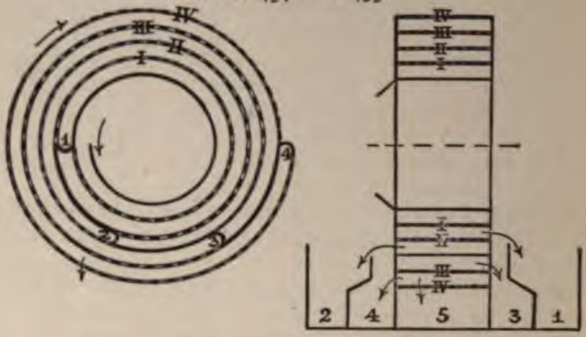
* N. E. I. xxxviii. 183.

The coal to be separated is delivered into the central part, which is a cone-shaped circle larger in diameter in its outer end, to facilitate the delivery of the larger pieces of coal which do not pass through the first series of holes. The coal passing through the first holes falls into the second division, 2, and by the revolution of the screen is separated, the pieces too large to pass through the second series of holes being retained upon the plate until they reach a point in the circumference where a channel receives them, down where they are discharged out of the side of the screen. The coals passing through the holes in division 2 are further separated, a portion passing through plate 3. All, however, that remains on this plate is discharged when the point 3 comes opposite the channel in the circumference. The same process goes on until finally all the remaining coal is discharged through plate 4.

FIGS. 454 AND 455.



It is claimed for this device that it is smaller than an ordinary revolving screen, that the space occupied is less, that the coal is not broken nearly so much, a saving of from 6 to 7 per cent. being experienced as compared with old types, and that the screening into the required sizes is most effectively done. The speed of rotation varies from 6 to 8 times a minute, and with a screen 7 ft. 6 in. diameter, by 4 ft. long, 50 tons an hour can be treated.

Greenwell's Screen.—This screen* consists of a number of parallel endless chains which travel between angular bars of varying sections suitable for the size of coal to be made, and diminishing from the top of the screen. The bars are fixed, but the chain travels at a speed of 70 feet per minute, and as the coal is carried forward it falls between the chains and fixed bars. The dirt is picked out as the coal travels along. The advantages claimed are (1) small first cost and the small cost of repairs; (2) the small height taken up; (3) as the chains are level there is little breakage.

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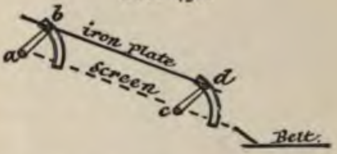
* Brit. Soc. Min. Stud. xiii. 95.

Varying the Sizes made by Screens.—In consequence of the exigencies of trade, different sizes of coals are often required, and such change cannot be made exact by varying the spaces between the bars or altering the size of the mesh. With wire netting screens, the only way to make the change is to stop the screen, take out the one riddle and replace it by another.

Plating.—It sometimes happens that unscreened coal is required—that is to say, in the state it comes from the mine, with none of the fine removed. In such cases a method of "plating" the screen is employed. At Hilda Colliery this is done by an arrangement of cranks, *a b*, *c d* (Fig. 456), turning about centres, *a* and *c*. These cranks support a plate which, when not in use, stands 6 or 7 in. above the screen grating. If these cranks are turned, the plate is lowered on to the screen and closes up all the openings. The guides for the plate are curved, as the cranks in rising or falling necessarily describe the arc of a circle.

FIG. 456.

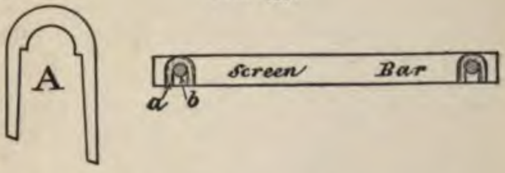


Combs.—With the ordinary bar screen, if one size is being made and another required, the screen has to be stopped, and the bars pulled out and replaced by others. To render this operation easy, the bars are usually threaded in a kind of comb which, in its turn, is dropped into and held in position by a shoe on each end. To alter the size of coal being made, the bars are lifted out of the comb, which is then replaced by another one having openings of a different width, into which the bars are replaced.

A better plan than this is that of employing a square bar, on each side of which is attached a comb having different sized slots. Here to make an alteration, the screen bars are lifted out, and the comb bars turned over until the proper-sized openings are upwards.

In other places a circular piece is cut out of the end of each bar which rests on a circular shaft, *b* (Fig. 457). The spaces between the bars are kept by horseshoe washers, *a*, which can be added to or removed quite easily. One of these washers is shown enlarged at A.

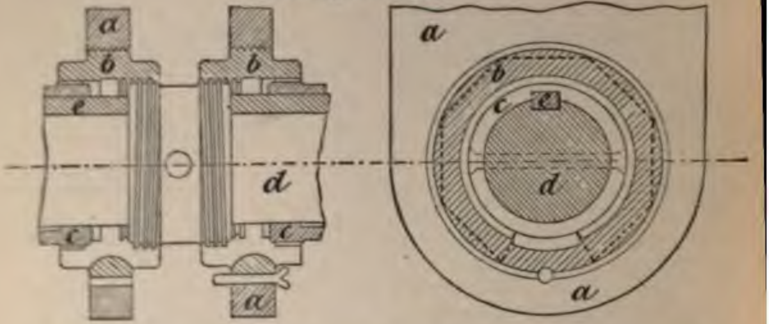
FIG. 457.



Variable Cross-bars.—All the preceding arrangements possess some objectionable points. Not only is there a considerable loss of time, but in putting up or pulling down, the bars often become altered and get bent and strained. To avoid these inconveniences, Messrs. Guinotte and Briart have designed the arrangement represented in Figs. 458–460, by means of which the spaces between the bars can be instantaneously varied without stopping work.

The screen bars, *a a* (Figs. 458 and 459), are carried by spindles, *b b*, threaded with right- and left-hand screws, which carry the sleeves or nuts, *c c*, having threads cut in the opposite direction. The direction is the same for all the screws and nuts, and all the sleeves are threaded on the shaft, *d*, common to the whole system (see Figs. 448–451), the two being connected together by the key, *e*, fitted into a key-way running along the whole length of the shaft. The sleeves, *c c*, are otherwise free; they turn with the shaft, but can glide longitudinally upon it. If the shaft, *d*, is turned, the sleeves and spindles rotate, and consequently the separation of two consecutive bars will augment and diminish according to the direction of rotation.

Figs. 458 and 459.

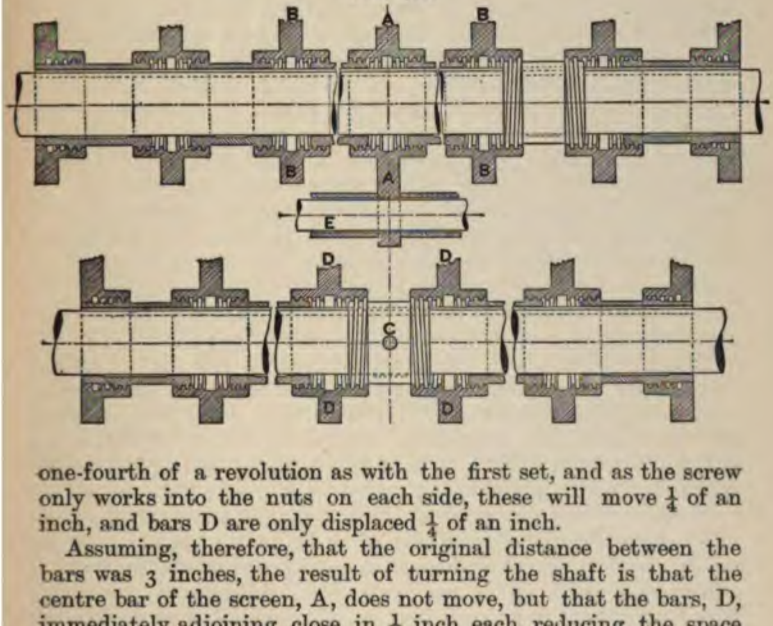


If one of these nuts is bolted upon the shaft, the bars would be displaced on either side of it, in amounts proportional to their distance from the fixed point, or the same thing may be done by fixing one bar.

Fig. 460 shows how the bars are connected amongst themselves, and renders clear how the same relative distance is retained after varying the original opening. To prevent confusion, the two sets of bars are drawn one above the other. Taking the upper set first: the middle bar, A, is *wedged* in the centre of the screen as it is keyed to the shaft, E; consequently, when the shaft, *d* (Fig. 458), is rotated, this bar does not move, and the nut, *b* (Fig. 458), remains at rest, but as the shaft turns, it necessarily follows that the screw, *c*, enters the nut, while at the same time, the other end of the screw, *c*, enters the nut, *b* (Fig. 458), of screen bars, B (Fig. 460). As a result, bars B move towards A, a distance *double* that due to the pitch of the screw. That is to say, if the pitch is 1 inch, and the shaft, *d* (Fig, 458), make one-fourth of a revolution, the bars, B (Fig. 460), will move a total distance of ½ an inch.

These bars, however, are not the ones nearest to the central bar A, as those of the lower set, D D, adjoin A. If this set be now considered, it will be noticed that, instead of a bar being fixed, the screw, *c* (Fig. 458), is wedged on the shaft by a bolt, C (Fig. 460), passing through it. Consequently, when the shaft is rotated, the screw turns with it and travels into the nuts on bars, D D, dragging them towards the centre. Here the shaft makes one-fourth of a revolution as with the first set, and as the screw only works into the nuts on each side, these will move ¼ of an inch, and bars D are only displaced ¼ of an inch.

FIG. 460.



Assuming, therefore, that the original distance between the bars was 3 inches, the result of turning the shaft is that the centre bar of the screen, A, does not move, but that the bars, D, immediately adjoining close in ¼ inch each, reducing the space between the bars to 2¾ inches. The bars, B, which are the next adjoining ones to D, were originally 6 inches from A, but as they move ½ an inch, are now 5½ inches away. D is 2¾ inches away from A, and, consequently, 2¾ inches away from B. Thus the distance between the bars has been altered from 3 to 2¾ inches.

The other bars of each set move towards the centre in amounts proportional to their distance from it. The further they are away, the greater is their motion, as they are dragged a distance equal to the sum of the motion of all the right- and left-hand screws.

The distance between the bars is indicated at the extremity of the shafts by a graduated dial. With the aid of these cross-bars, without stopping the working, any variation in size required for trade purposes can be readily obtained, within the limits allowed for in construction, this being determined beforehand, and as the movement is performed by simply pulling a lever and noting a finger on a dial, any workman can do it.

The cost is high, owing to careful construction and fitting required, but there is little wear, and the results obtained compensate for the additional outlay.

Belts.—After separation by the screen, the various sizes of large coal are received upon belts, by the side of which attendants are stationed to pick out dirt and stones with which the coal is associated. The length of these belts is dependent to a great extent on the nature of the coal and trade of the district, but in all cases is greater, the dirtier the coal. In the Midlands, where several qualities of large coal are made, all of which are loaded together down the mine, it was at one time the common practice to wheel each tub from railway waggon to waggon, picking out the various qualities. This practice has been superseded by the employment of travelling belts. All the coal from the mine is tipped on to one end and gradually passes in front of a row of attendants, who pick out the qualities required for the trucks they are loading, and let the remainder pass by to be taken off further on by other attendants loading different qualities. To enable many waggons to be loaded at one time, the belts are made proportionately long, frequently from 200 to 300 ft.

These belts, however, are more for sorting the coal than for cleaning it. For the latter purpose, even with the dirtiest seams, they rarely exceed 60 or 70 ft. The width of the belt is governed by the length the attendants can easily reach. If they are stationed on both sides, 4 ft. 6 in. is a common width, but better results are perhaps obtained with only 4 ft.

Belts may be constructed in several different ways. The form most generally in use consists of steel plates attached to an endless chain. These chains are usually made of alternate single and double links, which are preferably connected to the plates forming the belt by being bolted to angle-irons which are riveted to the plates. This construction allows a plate to be taken out and replaced without cutting any rivets, as would have to be done if the links of the chain were riveted direct to the plates.

A construction largely employed in Lancashire is to rivet pieces of angle-iron (*a*, Figs. 461 and 462) to each plate and to bolt the link, *b*, to them. The links of one plate overlap those of the other, and a bolt, *c*, is passed from the links on one side of the plate to those on the other, thereby forming the hinge around which the plates turn, when they arrive at the driving tumbler or sprocket-wheel. Sometimes the plates are secured to the driving chain by a hooked bolt, which passes through a hole in the links and is secured on the top of the plate by a nut.

These belts are driven by tumblers which have their arms shaped to engage with the links. This system of driving, with any average load, has been found to give better results than an octagonal drum, which is sometimes employed. Belts may either be driven from the "leading," or "following" end, both of which are equally efficient, unless the load carried is a very heavy one; as the "following" end is more conveniently situated to the motive power they are usually driven from it. They are supported at intervals by rollers (*a*, Fig. 463), which serve the double purpose of lessening the power required to move them and of preventing any sag, and, as an additional support, the edges travel in an angle-iron slide, *b*. To reduce friction, rollers are sometimes provided at the sides of the plates (Fig. 464), these running in the angle-iron guide already referred to.

FIGS. 461 AND 462.

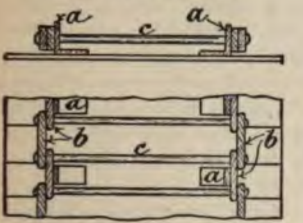


FIG. 463.

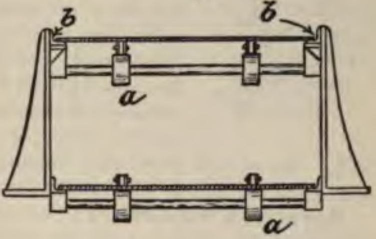
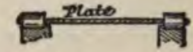
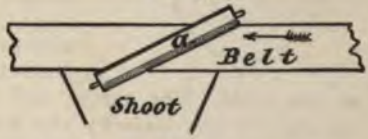


FIG. 464.



To readily remove the dirt picked out of the coal, many belts are provided with a partition in the middle, consisting of two angle-irons riveted to the plate. The attendants pick out the dirt and deposit it in this trough. The dirt is then carried along with the coal, but separate from it, and discharged down a shoot at the end. Where this is employed, the shoot leading from the screen is provided with a V-guard, which prevents the coal passing into the central trough, and directs it to the two sides of the belt.

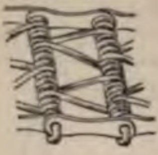
FIG. 465.



For delivering coal from belts at points along their length the arrangement shown in Fig. 465 is applied at Aldwarke Main Colliery. A roller, *a*, is placed diagonally across the belt at any point where delivery is required and sweeps off the coal into the shoot. This roller travels in guides, and can be raised and lowered to give intermittent delivery.

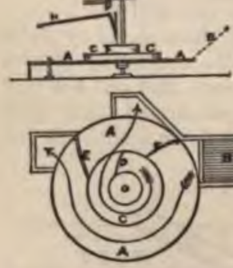
Many materials, such as hemp, wire ropes, &c., have been used in the construction of picking belts, but have not received much favour. In Lancashire, belts constructed of woven wire netting are largely employed and possess one marked advantage, as they rid the coal from any fine which has not been removed during the passage over the screen. Some coals have small pieces of dirt adhering to them, and these have to be chipped off by the attendants. A quantity of small is produced which, if solid belts are employed, is carried away with the large coal, but if wire gauze ones are in use, the small pieces fall through and a more efficient separation results. These belts are built up in several ways; a common form is shown in Fig. 466. They are obviously unsuitable for carrying the smaller qualities, for which plate-belts can only be used.

FIG. 466.



Revolving Tables.—To economise the large amount of space occupied by cleaning belts, circular picking-tables are often employed. They generally consist of a horizontal circular plate revolving about a vertical axis. The centre part of the plate is made higher than the circumference where the coal is delivered. All the dirt picked out is thrown on to this shelf near the centre and removed from time to time, while the coal is discharged at any convenient point by a scraper.

FIGS. 467 AND 468.



An improved arrangement, designed by Mr. Wm. Haydock, is in use at Abram Colliery, where a mixture of coal and cannel has to be very carefully sorted. A circular table (A, Figs. 467 and 468), is keyed on a vertical shaft driven by bevelled gearing, and in the centre is a raised platform, or boss, C, upon which the picked material is placed by hand. Curved scrapers (E and F, Fig. 468), working on hinges at the circumference, are provided, and these direct the qualities made into their respective shoots; D is a scraper (which can be moved up and down by an overhead lever, H) on the raised portion, and is used to turn the material off this part on to the table. The mixed coal and cannel is delivered on to the edge of the table by the screen, B, and the material which occurs in the smallest quantity is picked out and deposited on the raised platform, C, that is to say, if coal and cannel are being sorted and coal predominates, then the cannel will be picked out. The table revolves and brings the material up against the scraper, E, which sweeps it off into the shoot, as shown by the arrow. The cannel on the raised platform is swept off by the scraper, D, and directed into its proper shoot by the hinge, F. The tables are 12 ft. to 15 ft. in diameter, and make about 1½ revolutions per minute. If a cannel truck is not in position under the shoot, this mineral can be allowed to accumulate on the platform, C, by raising the scraper, D.

Loading Shoots.—When the coal reaches the end of the belt, it is directed down a shoot into a waggon. These shoots, if fixed, have to be placed at such an inclination that the coal readily slides down them, and towards the end it attains considerable velocity, dashing violently into the bottom of the truck and causing considerable breakage. With a tender coal this becomes a serious matter, and numerous attempts have been made to minimise the damage.

FIG. 469.

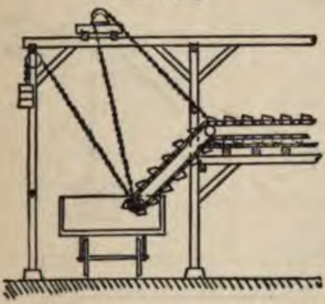
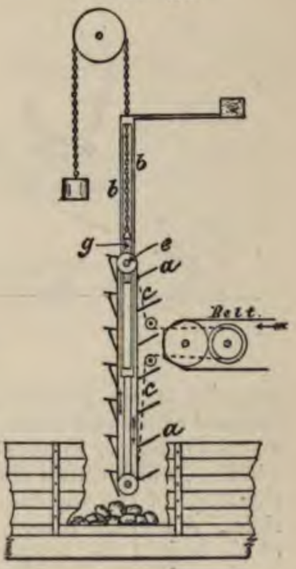


FIG. 470.



A common procedure on the Continent is to make the shoot a series of plates, which travel along as a belt; indeed, it may be considered a belt, but instead of the plates being flat, each one is of angle form. The vertical ridges effectually prevent the coal slipping (Fig. 469). Each lump is gradually taken down the slope and deposited in the truck. The leading end is carried by a movable jib, and can be raised or lowered to suit the height of coal in the waggon.

An ingenious coal-lowering apparatus has been introduced by Mr. C. Soar.* It consists of a series of hinged shelves (*a*, Fig. 470), bolted to pitch chains, which are driven in the direction shown by the arrows by an endless driving chain, shown by the dotted line, *c*, actuated from the drum-shaft of the picking band.

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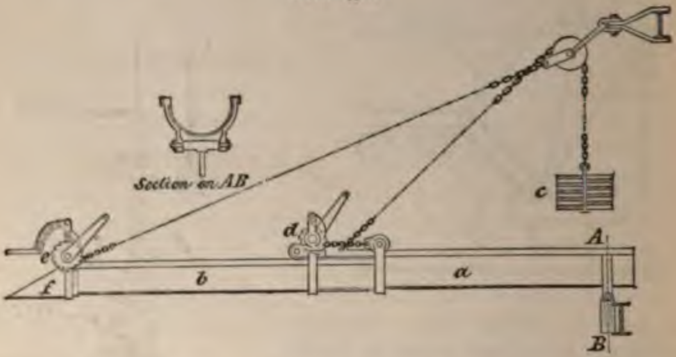
* Fed. Inst. i. 183.

at such a speed that, as the belt delivers the coal from its end, a shelf is always in a proper position to receive it. The top shaft, *e*, works in two travel blocks, *g*, which travel up and down between the fixed guide bars, *b*. The whole apparatus can be raised or lowered, and held in any position, by a rope attached to a winch. The coal has no greater distance to fall when the truck is empty than when full, and is put down as if by hand.

An excellent loading shoot is employed at Bascoup, It can be turned about its point of support and lengthened or shortened at will by means of a suitable arrangement. The part *a* (Fig. 471), can slide in the part *b*. A counterpoise, *c*, whose chain is fixed to the part *a*, balances the entire shoot when at its minimum length. The variation of the length is made by a small windlass, *d*, mounted at the extremity of the part *a*, and whose chain is fastened to the end of the part *b*. A second windlass fixed to it allows the hopper to be raised or lowered at will; the chain of the windlass, which causes the part *a* to enter the part *b*, stretches the chain of the windlass, *d*, thus making the whole perfectly rigid. A movable nose, *f*, also allows a discharge at two points of the axis of the hopper without displacing it; this nose has another *rôle*, playing the part of a stopper and regulating the discharge.

FIG. 471.

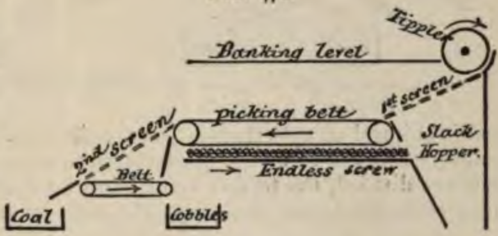


With the aid of this telescopic shoot, the coal can be directed on to any part of a waggon's surface, practically without any drop. Not only does this save expense, one man doing the work, but the most tender coal can be loaded without breakage. It is necessary that the shoot should be kept full of material.

TYPICAL ILLUSTRATIONS.—Having described the different parts of a screening establishment, a description of several arrangements as applied at collieries is given to illustrate the way they are combined amongst themselves. To a certain extent, any desired arrangement can be made, the one adopted depending, as has been before remarked, upon the conditions locally existing at the colliery, the amount to be treated, and the quantity and nature of the refuse.

Pemberton Colliery.—The screens here have fixed bars. All the tubs are tipped on to the first one, which removes the slack, this falling into a hopper. All that passes over this screen is conveyed by a shoot on to a travelling wire picking belt. During the passage of the coal along the belt, any dirt is removed by hand-picking, and any fine particles which have escaped falling through the first screen pass through the opening in this wire belt, and fall into a trough with sloping sides, in the bottom of which is an endless screw, which by its revolutions carries the slack into its proper hopper (Fig. 472). The round coal, on reaching the end of the picking belt, falls on to a second screen, which separates it into two qualities; the larger size passing over the screen drops at once into a railway waggon, while the cobbles which pass through this screen fall on to a travelling belt made of iron plates, and are conveyed to another truck. The arrows indicate the direction which the coal takes.

FIG. 472.



Brinsop Hall Colliery.—At the Arley Mine Pit, the coal, after passing over a screen, is carried along by a steel-wire picking belt, 16 ft. long by 4 ft. wide, and having a mesh 1½ in. by ¼ in. To do away with the disadvantage of fixed screens, the lower portion of the bars are made movable by the arrangement already described. The screen is divided into two portions by a movable plate, about 14 inches broad, working on a hinge at its upper end. By means of the hinged plate, the coal can be steadied on to the bars, and, in addition, a vertical rake-stop is provided for the same purpose. The bars above this plate have an inclination of 14½ in. to the yard, while that of the lower ones is 19½ in. to the yard.

Running the entire length of the picking belt and on both sides, are fixed two planks on which the chipping is done; all the slack produced by this operation falls through the wire meshes and passes down a shoot into the slack waggon. At the end of the belt a second screen is fixed with bars about 4 in. apart, which takes out the cobbles, the remainder passing into the coal trucks.

All the dirt and inferior coal is picked off the wire belt and thrown on to another travelling belt running by the side of the first one, about 20 ft. away, but placed at a slightly higher inclination. Fig. 473 shows an elevation of the entire installation, while Fig. 474 gives a cross-section of the arrangement of the belts. These dirt belts are formed of old flat steel-wire ropes lying side by side, and are about 15 in. broad and 37 ft. long. Any good coal is chipped off and thrown down a shoot on to the second main screen, while the dirt and inferior coal pass on to the end where they are divided, the former being directed down a side shoot into tubs, while the latter passes over the end into land sale carts.

FIG. 473.

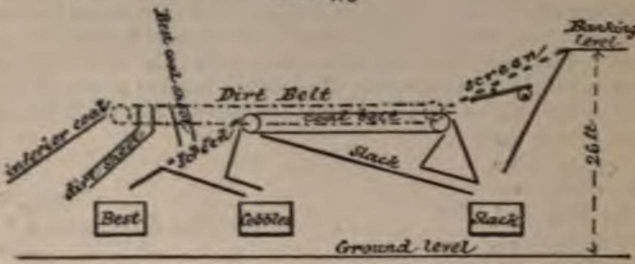


FIG. 474.

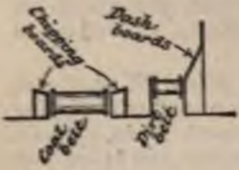
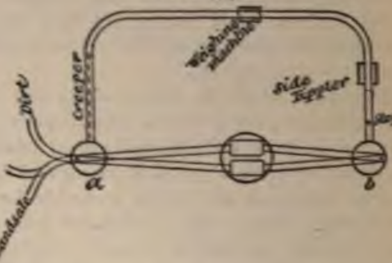


FIG. 475.



Hilda Colliery.—This colliery is situated in the centre of a town, and the arrangement of the heapstead affords a fine illustration of what can be done in a confined space if required. On leaving the cage the tubs gravitate to a turntable (*a*, Fig. 475), and can either be passed to two tipplers used for land sale; to a third road, if dirt or refuse; or to a fourth road, if for the screens, where they are caught by a creeper and lifted up to such a height that when released they run by gravity on to the weighing machine, where they are automatically arrested by an arrangement shown in Fig. 476. A rod, *a b c*, is slung from a convenient place, *a*, the end, *c*, being kept in position by its own weight and prevented falling to the ground by the collar, *d*, on the vertical rod. A tub is shown held in position on the weighing machine. The next tub coming in the direction indicated by the arrow, strikes the rod near the point, *b*, and as it proceeds down the rails lifts up the end, *c*, and releases the first tub. As soon, however, as the back end of the tub passes the point, *b*, the link drops down and locks the tub, keeping it on the machine until the succeeding tub releases it.

FIG. 476.

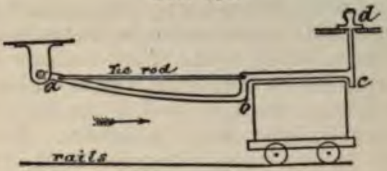
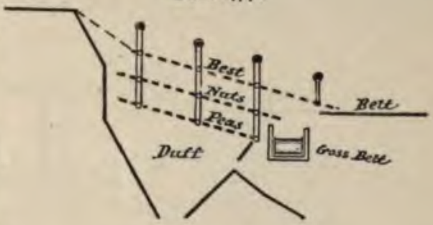


FIG. 477.



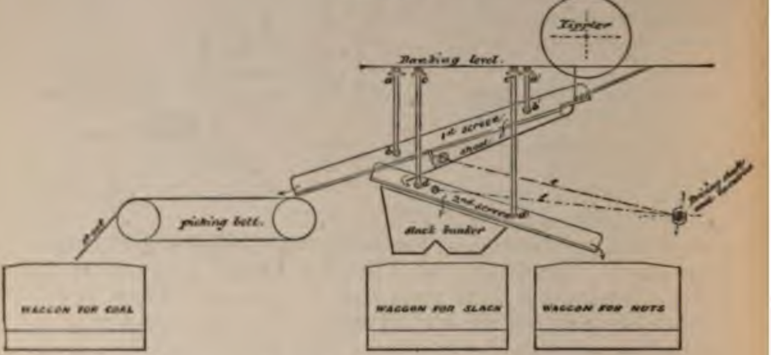
After the tubs are weighed they run on to a machine-driven side tippler and are discharged, thence proceeding to a second turntable (*b*, Fig. 475), and being turned through a right angle; thence to the shaft. The whole area of the flat sheets is about 60 ft. by 45 ft., *a* being about 18 ft. away from the pit, and *b* about 15 ft.

After being tipped, the coal is received into a regulating hopper, and thence passes on to a wire-gauze jigging-screen, in which three gauzes are superimposed one above the other (Fig. 477). The first takes out large coal and delivers it on to a picking belt; the second, which has a mesh $\frac{5}{8}$ inch square, separates nuts, which are delivered on to a small cross-belt, and from thence to a picking-belt running parallel with the main belt; while the third gauze separates the remainder into peas and duff, or fine. By an arrangement of traps, the nuts and peas can be remixed and loaded as one class of coal, and the peas and duff as another, or, if required, all three can be combined; in addition, the top screen can be plated and unscreened coal made and loaded at the far end of the main belt, a reversible trap being provided there for such purpose.

Placing the screens one below the other, without any shoots to conduct the material passing through one screen on to the head of the screen immediately below, saves an amount of vertical space; but the sorting cannot be so accurate as is desirable, as the coal which falls through near the base of the top screen scarcely passes over the next screen at all, but at once goes to its shoot. If all the coal has to be delivered to the top of each screen, the banking level must be a considerable height above the ground, but to overcome this disadvantage a common practice in the Yorkshire coalfield is to convey the coal from the base of one screen to the top of the next one by means of conveyors similar to those already described.

Hewlett Pit.—At the No. 2 shaft two separate shaking screens are fixed. The general arrangement will be seen from Fig. 478. The coal is tipped on to the first screen, to which a rocking motion is imparted by means of an eccentric and rod, *e*, the screen being suspended by four arms, two of which are shown at *a b* and *a' b'*. This first screen is fixed at an inclination of 14 in. to the yard, and the meshes are 1 in. square. The round coal passing over it falls on to a wire picking belt fixed in the same line as the screen

FIG. 478.



where the best (merchants') coal is picked off, the cobbles passing over the end into a truck. All the material passing through the first screen is conveyed by a shoot to the head of a second screen, suspended by the arms, *c d*, *c' d'*, which also receive a reciprocating motion by an arm, *f*, and eccentric keyed on the same shaft as the first one. The meshes here are ½ in. square, and the mineral is divided into nuts and slack.

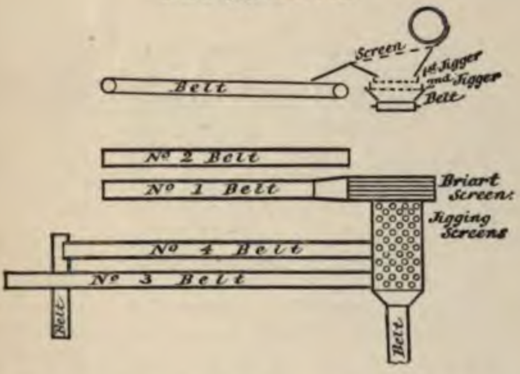
Aniche Colliery, France.—Only one tippler is used, this being a machine-driven side-tip one, and all the coal is turned on to a Briart screen, placed on a small inclination. The large coal passing over this screen is conveyed down a shoot on to a travelling hempen picking belt, No. 1, which carries it to a railway truck. During its passage there the coal is sorted by hand into two sizes, part being placed on the No. 2 belt (Figs. 479 and 480).

All the coal passing through the screen with oscillating bars falls on to a jigging-screen (No. 1), worked from an eccentric in the ordinary manner; this screen is fixed at right angles to the first one, and the motion is sideways. All the coal passing over is carried on to belt No. 3; all that falls through drops on to a second jigger fixed immediately below the first, and exactly similar to it, except that the holes are smaller. The small coal passes through, falls on to a belt, and is at once conveyed to the trucks; the larger coal passes over the screen and drops on to a travelling belt, No. 4, which runs parallel to No. 3, and at right angles to the screen.

The coal from the first shaker-screen is taken by the belt directly to a waggon, but that from the second screen after being carried along on its picking belt, falls on to another belt at right angles, and is conveyed to its proper waggon.

A noticeable feature about all the jigging-screens which the author has seen on the Continent, is the fact that they are made of perforated sheet iron with circular holes, no wire netting, either with square or circular holes, having been met with. The advantage of circular holes seems to be that only the proper sized particles can pass through; with square holes, the diagonal line is longer than the sides, and larger pieces than the square of the mesh can fall through.

FIGS. 479 AND 480.

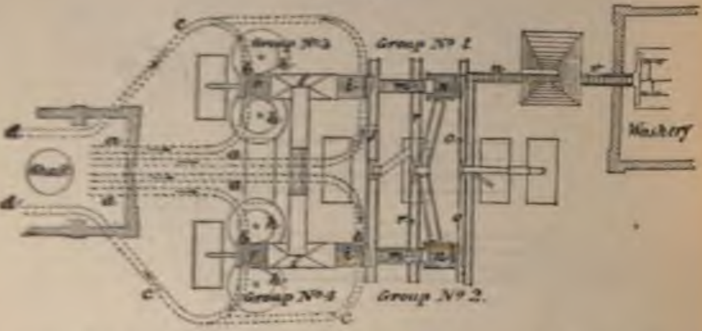


No. 5 Pit, Bascoup.—The collieries of Mariemont and Bascoup possess very complete screening-plants, which allow the different kinds of coal to be easily separated and classified. That at No. 5 Pit, Bascoup, is the most recent and complete one. It is shown in plan and sectional elevation in Figs. 481 and 482. The former is to scale, while the latter, for the sake of clearness, is a diagrammatic representation. The screens, picking belts, &c., are situated in a building, 142 feet in length, and 92 feet in width, placed in the axis of the pit frame. The building comprises three levels or stages. (1st) The upper floor is used entirely for the haulage of full and empty tubs, and inclines towards the

winding shaft, so as to allow the waggons to return there by gravity. (2nd) The intermediate stage is horizontal; it is at this level that the handling (sorting of the coal, &c.) is done and where the principal supervision is required. (3rd) The railway level or charging floor. The freight roads are not horizontal, being inclined in various ways in order to facilitate the handling of the waggons.

Circulation of Tubs on the Upper Floor.—As soon as the tubs come off the cage, they are pushed on to one of the four ways (*a*, Fig. 481), and conducted by a creeper chain to the top of an inclined plane whose summit is at the commencement of the curve leading to the tippler. At this point the tubs disengage themselves from the chain and continue running, partly by the acquired velocity, which is very feeble, however, and partly by the action of their own weight. The height of the incline is determined experimentally, so that the waggon stops on arriving at the tippler, *b*. Each succeeding tub pushes away the one that has just been emptied. The empty tubs gravitate down the roads, *c*, to the rear of the shaft at *d*. The direction of motion is shown by the arrows.

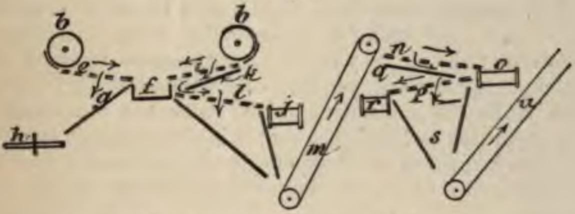
FIG. 481.



Screens making Two Sizes.—The two groups of apparatus, Nos. 3 and 4, make two sizes, large and "*tout-venant.*" From the tippler, *b*, the coal falls upon the Briart screens, *e*, inclined at 10°; the large coal remaining upon the sieve passes into the hopper, *f*, inclined at 22°, from which it is conducted to the loading place. The coal passing through the screen is received upon a shaking shoot, *g*, which throws it upon two revolving picking tables, *h*, where the dirt is removed; the coal falls into a loading hopper.

Screens making Five Classifications.—The two groups of apparatus, Nos. 1 and 2, are much more complete than those just described. They make five sizes: large, "*gailleteries, gailletins,* *têtes de moineaux*,"* and fine. From the tippler, *b*, the coal is emptied on to the first Briart screen, *i*, inclined at 10°; this retains the large coal, which passes into the hopper, *f*, where it unites with that furnished by Nos. 3 and 4. That which passes through the screens is received upon a shaking shoot, *k*, inclined at 15°, which leads the coal to the commencement of a second Briart horizontal screen, *l*. The "*gailleteries*" which pass over the screen are pushed on to the cleaning belt, *j*, and carried into the loading hoppers, from which they are put into trucks. All the coal passing through the second sieve, *l*, falls down a shoot and is lifted by a bucket elevator, *m*, and delivered on to the third screen, *n*. This is horizontal, and retains the "*gailletins*," which then go to the belt, *o*, by means of which they are conducted into a loading hopper in the same way as "*gailleteries*." The same hopper also receives the *gailletins* furnished by the other screen of this group. Finally, a fourth screen, *p*, receives that which falls through the third, by the aid of a shaking table, *q*. The "*têtes de moineaux*," which pass over screen *p*, are received on a cleaning belt, *r*, and conducted to the centre of the work-shed, where they can either be loaded in a truck or sent back again by a second belt towards the screen, and mixed with the fine after it has been washed, the course adopted depending on the demands of trade.

FIG. 482.



The fine, which passes the four screens, falls into the hopper, *s*, from which it can either be loaded directly into trucks by a shoot, or sent to the washer by means of the conveyor and bucket elevators, *u* and *v*, which deliver it on to a reciprocating table, where a further sizing takes place, to be described later on. The fine, instead of being transported by belts, and loaded at a central spot, like the *gailleteries*, *gailletins*, and *têtes de moineaux*, is either loaded into a waggon at the place where it is separated, or if destined for the washers, is sent there direct by belts, &c., from group No. 1. No. 2 group can also send its fine to the washers, but as it is rather removed from them, the small coal is taken by a belt to the bucket-elevator of the first group.

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* As it is imposible to give these sizes in their English equivalents, the technical names applied to them at the colliery are retained.

Washery.—All the coal destined for the washery, after being lifted by the bucket-elevator, is delivered upon a reciprocating table, formed of a series of perforated iron plates, arranged one below the other, which subdivide it into the following sizes: dust, from 0 to 5 mm., and grains, from 5 to 11, from 11 to 16, and from 16 to 25 mm. Each of these four sizes is washed separately in a manner similar to that described subsequently. The two former in felspar washers of the Coppée system, and the two latter in the nut-washers of the same firm. The three sizes, 5 to 11, 11 to 16, and 16 to 25 mm., are mixed together again after washing, and sold. About 40 tons per hour can be treated.

Cross Creek Collieries, Pennsylvania.—Anthracite coal cannot be sold in the state that it comes from the mine. Owing to its compact nature, and the practical absence of volatile matters in its composition, it will not burn well unless the lumps are nearly of a uniform size, and are free from dust. The method of preparing anthracite coal for the market is therefore entirely different from that adopted with bituminous varieties. Uniform and varied sizing is essential, in order that when the lumps are burnt the air may have a free passage between them. In addition, large amounts of slaty or argillaceous coal and carbonaceous shale are intimately mixed with the pure coal, and cannot be separated by hand-picking; it is also generally impossible to sell all the large coal as it comes from the mine. For these reasons, machinery has to be employed to break up the larger pieces.

The more recent and elaborate machinery employed in Pennsylvania, has been admirably described by Mr. E. B. Coxe,* but as his memoir covers 77 pages of printed matter and is illustrated by 43 plates, it is impossible to give anything but the briefest summary here.

The coal is first tipped on to a fixed bar screen, which allows most of the small coal to pass through. The large coal passes by shoots on to a movable bar screen, and all the small that falls through is joined to that obtained from the fixed bar screen. Up to this stage, practically only two sorts are made, each of which is treated separately. The lump coal is then divided into three sorts, the first being the shale and slate, which goes to the dirt heap; the second is pure coal, which is sold as lump-coal, if there is any market for it; the third product consists of pieces of coal and shale adhering to each other, and is too impure to go to market in its existing condition. Sometimes the shale can be chipped off with a pick, but more generally the mixture cannot be cleaned in this way, and has to be put through a set of crushing rolls, and then treated in gyrating screens, and the dirt picked out. The pure coal also passes through rolls, and is afterwards separated on gyrating screens, into several sizes or qualities, similar to those mentioned below.

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* Amer. Inst. M. E. xix. 398.

All the coal that has passed through the fixed and movable bar screens is conveyed to two screens, each of which make three sizes, called "steamboat," "broken," and "egg." The smaller coal passes to another pair of screens, known as the stove or wet screens (A), which are situated a little lower down. The steamboat coal from both screens passes into a picking-shoot, and from thence to a loading-shoot, provided all the steamboat coal can be sold. If it cannot, a portion is passed through a set of rolls, and separated by screens into "broken," "egg," "stove," "chestnut," "pea," buckwheat No. 1, No. 2, and No. 3, and dust.

All the coal which goes to the stove or wet screens (A), is divided there into stove, chestnut, pea, and No. 1, 2, and 3 buckwheat, and slime. These screens are worked wet—*i.e.*, a large amount of water is put on them, as the coal they treat contains mud and other impurities, and in order to make a good separation it is necessary to wash it. In addition, all the wet coal from this screen is cleaned in jigging coal-washers.

The movable bar screens are a modification of the Briart screen, arranged so that the bars only move up and down half as much as they move forward. With this construction the coal, although fed forward with rapidity, is not thrown up and down so much. The gyrating screens were designed by Mr. Coxe, and have been previously described.

The rolls employed for breaking the coal differ in one point from those generally adopted. The difference is in the form of the teeth. The rolls used are known as corrugated rolls, and the teeth are continuous from one end to the other. There are no points. The end of the tooth is slightly rounded, and the part doing the work is cast in chills, so as to give greater endurance. It is claimed that this type of roll breaks a lump of coal into two pieces of nearly the same size, while with rolls of ordinary construction the pointed teeth break the coal in much the same way as the stroke of a pick would do; that is, the lines of fracture radiate approximately from the point where the tooth strikes the lump of coal. Experience has also shown that separate rolls should be employed to break the coal into different sizes, as although all sizes below the size which is being broken are always made, yet the most economical method is to break any size as nearly as possible into the size immediately below it. In other words, it is more economical to break "lump" into "steamer," then break "steamer" as far as possible into "broken," the "broken" into "egg," and so on; of course, at each time eliminating all the coal below the size that you wish to break, before passing that size through the rolls.

Automatic shale-pickers are used in some parts of the establishment. They depend for their action on the fact that while the coal generally breaks into cubical masses, the pieces of shale of the same length and width are of much less thickness. Hence, if a quantity of shale and coal which has been passed through a screen and properly sized, the shale, if placed edgewise, would drop through a slit over which the coal would pass.

COAL WASHING.—Below a certain size it is impossible to pick out the dirt mixed with coal, and recourse has to be made to washing, for which a large variety of machines have been designed. Their principle and action are similar in every respect to those employed for ore dressing, but here it is the lighter material that is valuable. The theory of the subject is that bodies of different specific gravities fall through water at different velocities, the heavier more quickly than the lighter, that is to say, if both pieces are of approximately the same size; because it is obvious that a larger piece of a lighter material meets with as much resistance in passing through water as a small piece of a heavier material. For such reason a preliminary sizing should always take place before washing.

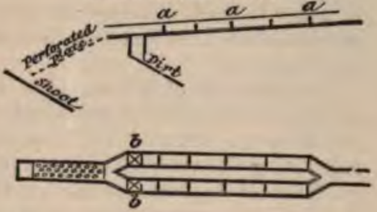
Sizing Apparatus.—The small coal which passes through the last screen is generally further subdivided, either by means of revolving sieves or trommels or reciprocating tables. The latter, perhaps, do the work better, but are not so convenient, as water cannot be employed; with trommels a stream of water is introduced and materially assists the operation. The disadvantage of a trommel having a mesh of varying size is that all the material has to pass over that part of the screen which has the finest mesh, and consequently the wear is considerable, but with such a soft substance as coal this objection is not very serious. It has been found that revolving screens require patching in the small (*fine*) portions about every year; their general life is somewhere from five to seven years, except when there is much sulphur present.

Revolving screens are unsuited for separating sizes below $\frac{1}{4}$ inch; and an apparatus which retains its German name, "*Spitzkasten*," is employed. It consists of a series of pyramidal boxes, upon whose sloping sides no material can settle. Each box is larger than the previous one. On entering the first trough, the speed of the water containing the material in suspension is checked, the particles of larger size settle down a little, and escape the velocity of the current, so that they soon reach the bottom of the trough.

The number of boxes determines the number of sizes made. A stop-cock is provided at the bottom of each box, through which the deposit can be swept out at any time by opening the tap; this device avoids any necessity for interrupting the main flow.

Trough Washers.—The first type of washer consisted of a trough, provided with a series of vertical stops, which prevent the coal and dirt passing on (Figs. 483 and 484). At the point where the coal is washed the supplying channel is divided into two; into each of these divisions the stream of unwashed coal can be directed at pleasure. As soon as one trough is full, the dirty coal and water is directed into the other, and a current of *clean* water turned into the first trough, while at the same time the deposits of coal which have accumu-ated against the stops, *a a*, are agitated by the attendants with rakes, with the result that the lighter coal is carried over the obstruction, while the dirt (pyrites principally), being of higher specific gravity, remains behind. The washed coal passes on to an inclined sieve, where all the water is drained away, and thence by a shoot into trucks. As soon as all the coal is removed from the washing troughs, a hole in the bottom (shown at *b b*, in Fig. 484) is opened at the lower end, the vertical stops are lifted out of position, and the accumulations of dirt are swept down and pass away through the hole, which is then closed up again. The vertical stops are returned, and as by this time the second trough contains a full charge of unwashed coal, the stream of dirty coal and water is diverted into the first trough, and a similar series of operations to those just described carried on in the second channel.

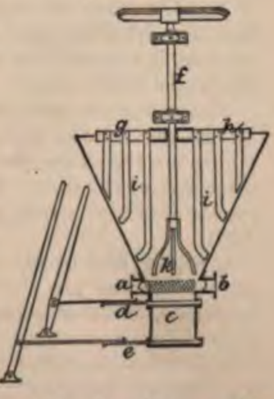
FIGS. 483 AND 484.



It is obvious that a large amount of labour is required. To reduce this charge, mechanically moved rakes are employed, the best form of which are those raking backwards, not forwards, or the unwashed material is likely to be pushed over the dam. The amount of water required is also very great, and the quantity of coal that can be treated is limited. Although the cost of working is large, yet up-keep and first cost are very low, and it appears that, under certain conditions, a trough washer gives as good results as any other form.

Robinson's Washer.—This well-known machine consists of an inverted truncated cone, with a diameter at the top about four times that of its diameter at the bottom (Fig. 485). At the base of the cone is fitted a water-jacket, *a b*, into which water under pressure can be brought, and which passes into the machine through a series of perforations placed all round the cone, the diameter of these holes being generally about ½ in. Still lower is a cylindrical chamber, *c*, controlled by two slides, *d* and *e*, movable

FIG. 485.



by the levers as shown. A strong shaft, *f*, is fixed vertically, exactly in the centre of the cone, and to it, through the medium of a cast-iron crosshead, are bolted four arms, two of which are shown at *g* and *h*. Each of these arms carries three iron bars, *i i*, projecting downwards and curved round at their lower extremity, in order to work close against the sides of the cone. The central vertical shaft terminates in four arms, *k*. Rotation is effected by bevel gearing.

The principle of this machine is the one common to all current classifiers—viz., that if two equal-sized particles of different specific gravities are allowed to drop through a stream of water, by regulating the velocity of the water it can be arranged that the particles of highest specific gravity shall continue to fall, while the lighter ones are driven upwards. Within certain limits, it is not necessary that the particles treated should be all of the same size, but it is perfectly clear that, unless some preliminary sizing takes place, there is a danger of either coal passing away with the water, or dirt being carried up with the coal, both of which results are unprofitable and undesirable.

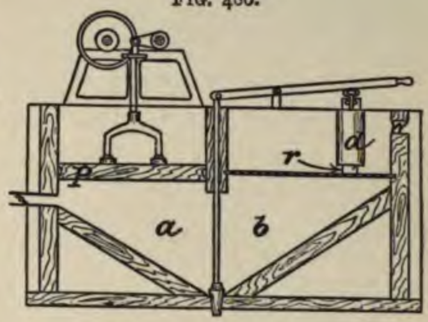
The actual operation of washing is conducted in the following manner: Coal is introduced at the top of the cone and falls into the water, and is kept in a state of agitation by the revolving arms. Situated some distance above the machine is a cistern, from which water under pressure is brought and introduced into the base of the cone through the pipes, *a* and *b*, the regular distribution being effected by the holes in the plates already alluded to. The water-pressure is so regulated that it is sufficient to lift up all the particles of coal and carry them over the top of the cone, while it is not strong enough to force up the dirt, which falls downwards and accumulates in the base of the cone. Its removal is effected by the two sliding doors. As a rule, *e* is closed. When the space between *e* and *d* is full, *d* is closed and *e* opened, and the dirt discharged. The washed coal, after passing away at the top, is received on a perforated plate, and the greater part of the water drains away.

The success of this machine depends to a very great measure on the carefulness and attention of the attendants. The chief points are the time given to flushing, and the regulation of the discharge of the dirt. The machine is compact and occupies little space; it is also strongly constructed and is not liable to break down.

Coppée Machine.—A great many of the very largest washing establishments are fitted either with the Coppée or Lührig machines, both of which are identical except in small details. Two different machines are used, one for washing the coal from ⅜-inch upwards, called the "nuts washer," and the other called the "felspar machine" for washing coal of sizes from ⅜-inch down to powder.

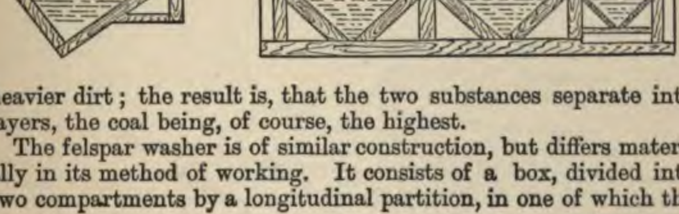
The nuts machine (Fig. 486) is of the ordinary continuous jig type, and consists of two compartments, *a* and *b*, in one of which the piston works, while the other is provided with a perforated strainer, slightly inclined from front to back. The piston, *p*, receives an up-and-down motion by being connected to cranks on a horizontal shaft, and the amount of this throw can be varied from $1\frac{3}{4}$ to 4 in. An opening, *w*, runs along the front of the washing compartment, and through this clean coal continuously passes away. The shale is discharged through a small cylindrical compartment, *d*, connected to the side of the casing, but which starts above the level of the strainer, leaving a free space between the strainer and the lowest end of the compartment of about 3 in. It is open at both ends and communicates with the outside of the machine through the opening, *r*. It is provided with a sliding door which regulates the discharge of the shale.

FIG. 486.



When the unwashed coal is introduced into the machine and the piston descends, it drives water into the compartment, *b*, and lifts the bed of the material resting on the strainer. On the return stroke, the heavier dirt falls faster than the lighter coal, while in the upstroke the lighter coal is lifted farther than the heavier dirt; the result is, that the two substances separate into layers, the coal being, of course, the highest.

FIGS. 487 AND 488.



The felspar washer is of similar construction, but differs materially in its method of working. It consists of a box, divided into two compartments by a longitudinal partition, in one of which the piston works as before (Figs. 487 and 488). It is also generally divided into two or sometimes three compartments in the direction of its length, each communicating with the other by openings, *o*, along the side, and through these the washed coal passes away. In the nuts washer, the holes through the sieve are smaller than the size of the material being treated, and consequently no discharge takes place through them. In the felspar machine, they are larger than the material, and the dirt passes through the sieve into the lower part of the apparatus. Three sieves are generally employed. The dirty coal is introduced at one end and gradually passes down over the remaining gratings, the clean material being finally discharged at the opposite end.

The chief peculiarity is the introduction of a layer of felspar, from two to three inches thick, on each sieve, whose specific gravity is greater than that of the material to be concentrated, and yet less than that of the gangue. The sizes of the particles of this bed are larger than the holes in the sieve. The whole framework of the machine is filled with water up to the level of each sieve, and as the pistons work up and down, a volume of water is forced through the holes in the bottom of each sieve, lifting the bed and the layer of material on it, and then allowing the whole to fall again on the return stroke. The lighter coal rises to the surface, and the heavier dirt gradually finds its way through the bed of felspar, when it falls into the bottom of the compartment to be removed from time to time. It is essential for thorough cleaning that the size of the felspar should be as small as allowable, and that the particles of mineral forming the bed should be of convenient density, have well defined rectilinear angles, and be of great durability to resist wear and tear. A point of considerable importance is the proper regulation of the delivery of water, which is controlled by a tap; upon this depends the progress of the material and the time it is operated upon.

For very dirty coal, perhaps no machine does its work so efficiently as this; indeed, every one gives it the character of removing dirt. It is, however, expensive in first cost, but requires little attention. Much depends upon the percentage of dirt originally present in the coal. If it is small, and, say, one-half of it is removed, the coke from the resulting product is a fair one; on the other hand, where the dirt amounts to from 15 to 30 per cent. and only 3 to 10 per cent. is taken away, the coke is very bad. With a dirty coal, probably it is best to use machines of this type.

FIG. 489.

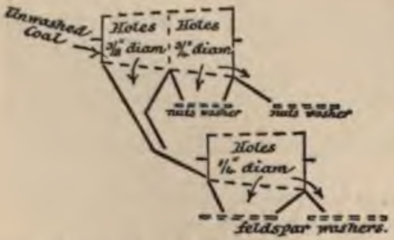


Fig. 489 gives a diagrammatic representation of a washery in South Wales treating about 200 tons per day. The fine coal from the screens (bars 1 in. apart) is raised by a bucket-elevator and delivered into a revolving screen, and separated into three portions: (1) the large, which passes over and goes to a "nuts" washer; (2) a size between ¾ and ⅜ in., also treated in a "nuts" washer; (3) the size below ⅜ in., which is carried off by a stream of water and delivered into a second revolving screen, having perforations ¼ in. diameter. Two sizes are made here—(1) ⅜ in. to ¼ in.; and (2) ¼ in. to nothing. These are washed separately and then re-united.

The nuts washers are situated a floor above the felspar machines, and all the coal from them after washing is delivered on to a pair of rolls and crushed, and is afterwards mixed with the washed coal from the felspar machines, the whole being raised by a bucket-elevator, and then carried by a revolving screw and stored in four bunkers, each holding about 40 tons. Each one is filled consecutively, and the discharge is so arranged that the coal stands in each as long as possible in order that the water may drain away.

One small engine, about 15 in. cylinder by 3 ft. stroke, does all the work, and there are only two men employed in the building—viz., an engineman who looks after the machinery on the first floor (engine, felspar washers, and pump), and an attendant who looks after the "nuts" machines and regulates the discharge into the bunkers. In addition, one man is employed outside to see that the slack is being delivered all right from the screens. The cost of an entire installation for washing 200 tons per day would be from £2000 to £2500. About 1000 gallons of water are lost per hour, this being, say, 10 per cent. of the total quantity used, and the life of a plant is variable, depending in a great measure in the way it is looked after. In bad cases it may be five years, in good fifteen years.

Conclusions.—The relative advantages of coal washing have been fully considered in a paper by Mr. R. de Soldenhoff* and in the discussion which followed. The interesting point is the absolute cost of washed coal, after charging the cost of the unwashed coal delivered to the machine. For example, a certain number of tons of coal are delivered to a washing machine, which if not washed would in the ordinary course of affairs be sold for a certain sum per ton, the impurities contained in them being weighed with the coal. During the process of washing the greater part of these impurities is removed, and the resulting product weighs considerably less (at Dowlais 4697 tons of unwashed produced 3433 tons of clean coal, the remainder was dirt and loss in washing; the latter amounting to 2.72 per cent. on the 4697 tons, or 3.59 per cent. on the 3433 tons). So many tons are actually lost which could have been sold at a certain rate, and these represent a certain sum of money which, being divided by the number of tons of *washed coal* recovered, gives a certain amount which must be added to the cost of washing.

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* So. Wales Inst. xiv. 88.

As the value of the unwashed coal increases, so does this charge, and a point may easily be reached where it neutralises the increased value of the washed product, especially if the coal is sold, not coked. In the latter case (coking) the advantages of producing coke with little ash are great, less flux is required for the furnace, and less slag is produced, and also less coal has to be handled. Washing might easily make an uncokable coal into a cokable one; as a very impure coal, although a caking one, may, owing to the large amount of ash in the coke, be unsaleable.

There is another point which must be specially noted: the same water must not be used over and over again for washing, without some efficient filtering arrangement, or the lustre of the coke will be completely lost. At Earnock Colliery, Lanarkshire, the water is pumped on to the top of the dirt-heap, and allowed to percolate through it before being used again. Settling tanks do not entirely remove the difficulty.

Dry Coal Cleaning.—Messrs Basiaux and Léonard* describe an apparatus for cleaning coal by means of an air blast at Rhein-Preussen Colliery, Germany. The coal is first separated by a trommel into five sizes, the largest of which, 1 to 2 inches in diameter, goes direct to the coke ovens; the others pass each to a separate cleaner, where the coal is spread out in a trough about 6 feet 9 inches long by 2 feet broad, divided by a horizontal perforated plate into an upper and lower chamber. One end of the trough is in communication with the air blast, the other with the cleaned coal dust-chamber, from which, however, it is separated by a sloping screen, the bottom end communicating with a hopper placed below the trough. In the lower compartment of the trough is an endless belt, which carries the coal to be cleaned in an opposite direction to the air blast.

The air blast blows the pure coal-dust through the screen, and the larger coal against the screen, down which it slides into a hopper, while the stones, too heavy to be affected by the blast, are carried forward by the endless band into another hopper.

The clean coal gave 7 per cent. of ash, and the stones (high) 45 per cent. of coal. The cost of cleaning (exclusive of interest and depreciation of capital) was given at 0.79*d.* per ton.

Briquettes.—On the Continent, the manufacture of briquettes as a means of utilising small coal is in great favour. English mining practice is probably further behind here than in any other operation. The great reason for this seems to have been the absence of a market, which was probably due to the uncompromising form of the article manufactured, although recently English firms have taken out patents for an improved mode of traversing and locking step by step a revolving mould-plate, which may be subdivided for interchanging moulds.

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* Rev. Univ. (2° Série) ix. 135.

Briquettes of the shape generally manufactured in England are unsuitable for domestic use. On the Continent every shape is made, varying from an ordinary brick to ovoidal perforated bullets about the size of a goose's egg; the former may be used for locomotive, and the latter for domestic purposes. Large quantities are made every year, and the demand is increasing. The only objection against them is the rather dense and nasty smoke produced on burning.

So much attention has been given to the subject, that the machines employed on the Continent seem to be a decided improvement on those used in this country. The one most in favour is that of Messrs. Bietrix & Co.,* who, after an experience of many years, have avoided the use of steam as a heating medium, finding that the presence of moisture should be avoided in the manufacture of homogeneous briquettes. In preparing the paste, the first procedure is to dry the coal in a small furnace, having a rotating plate for its bottom. The fire is placed on one side and passes over the coal and returns underneath the plate. During its passage through the furnace, the coal is turned over by means of rakes and vanes, and on its discharge is mixed with as small a quantity of pitch as possible, which has been brought there by an elevator.

The two substances are intimately mixed by a screw and conveyed on to the feeding plate of the machine, the chief feature of which is a horizontal mould-plate and double system of levers, by the aid of which the briquette is compressed on both sides. The rotating plate which contains the dies is provided with a series of short roller pegs projecting downwards, which engage at intervals with a screw-thread cut in a revolving shaft. In this way the plate is turned, and at each turn locked in position while the presses enter the die, motion only taking place when the plungers are out of the dies. The dies are attached to a beam connected at one end to geared cranks, while the other is attached to an hydraulic piston. The paste receives double compression, first by the top plunger and then by the bottom one. If any hard body gets into the press by accident, the hydraulic piston rises and prevents damage.

As the coal is first dried in a furnace, the briquettes contain a very small amount of moisture, and, in addition, less pitch is required, as the coal, to a certain extent, is softened. The machine is very simple and compact, one of the main features also being the certainty with which the coal and tar are mixed, this being a failing with many machines, pitch being very expensive. As the mould-plate is horizontal and has three of its holes exposed to the feed scrapers at one time, it is always properly charged. Double compression is admittedly such an advantage that every one at the present time uses it.

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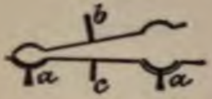
* Soc. Ind. Min. (2^{e} Série), xii. 461.

In the machines making ovoidal shapes, two plates are employed, the lower one fixed horizontally and the upper one inclined at an angle. The horizontal revolving plate on which the paste is fed is provided with two rows of egg-shaped cups (*a a*, Fig. 490), from the bottom of which project vertical spindles. The upper plate is provided with two rows of oval recesses which correspond with the cups in the lower plate. The two plates turn on shafts, *b* and *c*, and during the revolution approach each other, and at this moment the lower cups are raised up by a cam, which pushes up the spindles to which they are attached and by these means the briquettes are compressed. A little further on in the revolution the two plates separate again, and the cups being still further raised, the briquettes are discharged.

FIG. 490.



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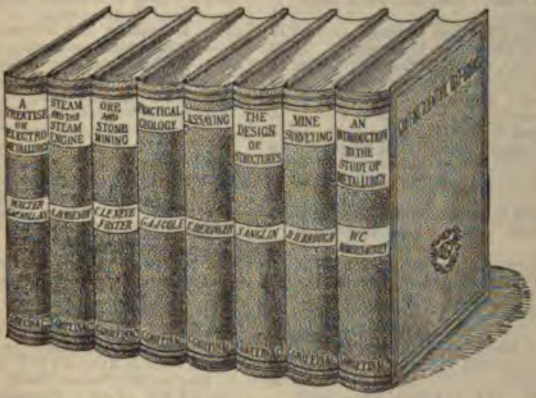

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